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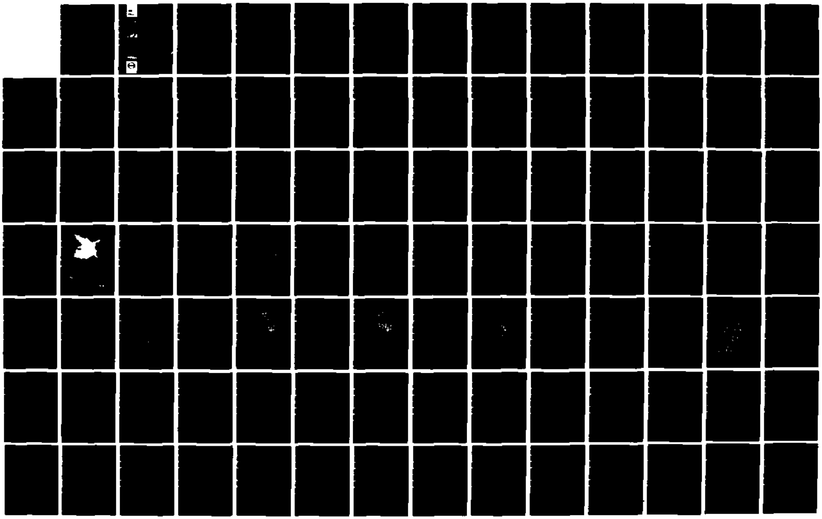

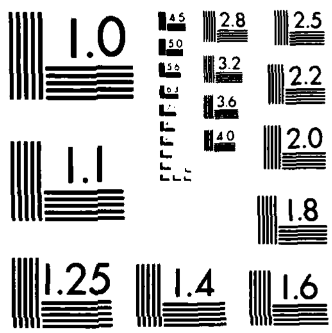

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ENVIRONMENTAL IMPACT RESEARCH PROGRAM

INSTRUCTION REPORT EL-85-2

RESTORATION OF PROBLEM SOIL MATERIALS AT CORPS OF ENGINEERS CONSTRUCTION SITES

by

Charles R. Lee, John G. Skogerboe, Kurt Eskew,
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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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May 1985
Final Report

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Information on vegetative restoration was compiled, reviewed, and a comprehensive report developed. Sources of information included US Environmental Protection Agency, US Department of Agriculture (USDA) Agricultural Research Service, USDA Soil Conservation Service, USDA Forest Service, US Army Corps of Engineers, US Federal Highway Administration, US Department of Energy-Bureau of Land Management, state highway departments, universities, and private industry.

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20. ABSTRACT (Continued).

This report contains information on the planning and implementation of vegetative restoration for problem soil materials at Corps of Engineers construction sites. Problem soil materials described include acid soils, saline and alkaline soils, excessively drained soils, poorly drained soils, dispersive clays, and wind-erodible soils. Plant materials are listed for different regions of the United States as well as information on seeding and planting procedures. The report should be a valuable resource document for planners and engineers that are required to control soil erosion and vegetate project sites that contain problem soil materials.

EXECUTIVE SUMMARY

The US Army Corps of Engineers (CE) is the largest water resource developer in the nation. As such, enormous quantities of soil material are disturbed at its many construction sites. Consequently, soil erosion is a major concern. Long-term soil erosion control measures for construction sites have emphasized the establishment of vegetation as quickly as possible following construction. This has often been difficult when problem soil materials are present such as those characterized as being acid, calcareous, saline, nutrient and organic matter deficient, or severely compacted. Much of the soil at these sites has been eroded away before adequate vegetation could be established.

Under the Environmental Impact Research Program (EIRP), the US Army Engineer Waterways Experiment Station (WES) has prepared an instruction report to provide effective long-term restoration techniques for problem soil materials encountered at CE project sites. Information on vegetative restoration was compiled, reviewed, and a comprehensive report developed. Sources of information included the US Environmental Protection Agency, US Department of Agriculture (USDA) Agricultural Research Service, USDA Soil Conservation Service, USDA Forest Service, US Army Corps of Engineers, US Federal Highway Administration, US Department of Energy, US Department of the Interior Bureau of Land Management, state highway departments, universities, and private industry.

This report provides guidance to all CE personnel and contractors for selecting appropriate and effective restoration techniques for controlling soil erosion, runoff water quality, and other long-term impacts at Corps sites. Guidance includes general considerations associated with soils, geology, and climate as well as detailed information relating to soil treatments for problem soil materials, site modifications, selection of plant species, establishment of vegetation, maintenance of vegetation, and land use. Emphasis is placed on long-term revegetation techniques and low-cost maintenance for upgrading and sustaining the biological potential of terrestrial problem soil materials within the context of land uses appropriate to the mission of the Army Corps of Engineers. Problem soil materials described include acid soils, saline and alkaline soils, excessively drained soils, poorly drained soils, dispersive clays, and wind-erodible soils. Plant species are listed for all regions of the United States and different soil types. Information

contained in this report may be used at all phases of a CE project including planning, engineering, construction, and operations. Examples of potential users are agronomists, soil scientists, landscape architects, resource managers, construction project managers, and contract specification writers. While this report was prepared in response to specific Corps needs, it has nationwide application and can be useful to other Federal, state, and local agencies. Information in this report can be applied to any soil material in any region of the country and may also have applications on contaminated areas and dredged material disposal sites.

PREFACE

This report was sponsored by the Office, Chief of Engineers (OCE), US Army, as part of the Environmental Impact Research Program (EIRP). The OCE Technical Monitors for EIRP were Dr. John Bushman, Mr. Earl E. Eiker, and Mr. David Mathis.

The first draft of the report (Instruction Report EL-83-1) was prepared by Hittman Associates, Inc., under Contract No. DACW39-80-C-0098 during the 1980-1982 time period. The authors of the draft report were Mr. Michael Clar, Mr. Robert Kort, and Dr. Homer Hopkins of Hittman Associates, Inc. In March 1983, the draft was submitted for field critique by Corps Districts and Divisions and for peer review. Based on the field experience and on review comments, major and final revision of the report was accomplished by Dr. Charles R. Lee, Mr. John G. Skogerboe, Lt. Kurt Eskew, Mr. Richard A. Price, and Dr. Norwood R. Page, Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Dr. Page prepared Appendix H and was instrumental in major revisions in various sections of the report.

The study was under the general supervision of Dr. Robert M. Engler, Chief, Ecological Effects and Regulatory Criteria Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, EL. Dr. Roger T. Saucier (EL) was EIRP Program Manager.

Appreciation is expressed to Dr. C. D. Foy, US Department of Agriculture-Agricultural Research Service (USDA-ARS), Beltsville, Md.; Dr. J. S. Boyce, US Geological Survey, Reston, Va.; Dr. F. T. Bingham, University of California, Riverside, Calif.; Mr. A. J. Palazzo, US Army Engineer Cold Regions Research Laboratory, Hanover, N. H.; Drs. A. D. Bradshaw, G. D. R. Parry, B. Bell, and M. S. Johnson, University of Liverpool, Liverpool, United Kingdom; and Dr. L. C. Bell, University of Queensland, Brisbane, Australia, for technical review of this report.

The valuable contributions made by the following Federal and state agencies and offices are also gratefully acknowledged: US Department of Agriculture (USDA) Soil Conservation Service Technical Service Centers in the western, midwest, south, and northeast regions; USDA Forest Service-SEAM Program and the Intermountain Forest and Range Experiment Station, Ogden, Utah; USDA-ARS, Beltsville, Md., and Las Cruces, N. Mex.; US Department of Interior Bureau of Land Management, Washington, D. C.; USDA Forest Service,

Northeastern Forest Experiment Station, Berea, Ky.; USDA Forest Service, Southern Region (Region 8), Atlanta, Ga.; US Department of Transportation, Federal Highway Administration, Washington, D. C., and Arlington, Va.; Virginia Soil and Water Conservation District Commissioners, Richmond; Delaware Department of Natural Resources, Dover; Ohio Cooperative Extension Service, Wooster; South Dakota Department of Agriculture; Nevada State Conservation Commission; Oregon Interagency Commission on Conservation and Forage Plantings; Northeast Illinois Commission; New Jersey Committee for Review and Development of Standards for Soil Erosion and Sediment Control; Maine Soil and Water Conservation Commission; and the State Soil Conservation Service Offices in: Arizona, Colorado, Iowa, Maryland, Minnesota, Montana, Nevada, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, and Texas.

Commanders and Directors of the WES during this study were COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Lee, C. R., et al. 1985. "Restoration of Problem Soil Materials at Corps of Engineers Construction Sites," Instruction Report EL-85-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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sites. In Sections II and III, emphasis is given to the need for applying different levels of effort to high priority and highly sensitive project sites as compared with that given to less critical sites.

(4) From Stage 1, Stage 2, and soil test information, identify the extent of potential problem soil materials at the project site.

(5) Read appropriate parts of Section IV for information on the specific problem soil material(s) identified.

(6) Complete Stage 3 - develop restoration plan in Section III (page III-13).

(7) Consider land uses (page III-18) prior to selection of vegetation for restoration from Appendix E.

(8) Read appropriate parts of Section IV for land treatment and soil conditioning measures specific to the problem soil material present at the project site.

(9) Consult Appendix D for specifications on techniques for soil stabilization after land treatment and soil conditioning measures have been completed.

(10) Consider the critical nature of the site to be restored, assign a priority, and decide on the level of effort and cost to be expended to restore the site.

(11) After the restoration plan has been developed and vegetation selection is completed, consult with local agricultural experts (Appendix G) for possible more up-to-date information and to discuss the plan.

(12) Implement plan.

Assumptions and Qualifying Statements

17. Hittman Associates, Inc. (Hittman), under contract to the Corps of Engineer Waterways Experiment Station, produced a draft report using the best available literature on revegetative techniques. There was a small amount of unpublished information used as well. It was recognized that the extensive unpublished information located in the files of various land management agencies and that which occurs undocumented in the minds of revegatative experts remain to be evaluated. Restrictions of time and budget made it impossible to access and evaluate these latter resources.

18. Primary emphasis was initially placed on the development of after-the-fact site restoration plans. Although some discussion is provided for the development of land restoration plans for new projects, it should be apparent that the information given herein is equally applicable to new projects. As pointed out in Section III, development of both types of plans must take place within the institutional requirements and policies already in place with respect to the upgrading and enhancement of land and water resources at project

a. Planning a new construction project.

(1) Read Section I.

(2) Locate occurrence of problem soil materials in Section II.

(3) Does location of project fall within any potential problem soil areas on Figures II-11 through II-17? If so, read appropriate description of problem soil material in Section II.

(4) Read Section III and follow Stage 1 and Stage 2 procedures.

(5) Read Appendix C, collect soil samples, and conduct soil tests according to Figure C-1, using test procedures referenced in Table C-1.

(6) From Stage 1, Stage 2, and soil test information, identify the extent of potential problem soil materials at the project site.

(7) Read appropriate parts of Section IV for information on the specific problem soil material(s) identified.

(8) Complete Stage 3 develop restoration plan in Section III (page III-13).

(9) Consider land uses (page III-18) prior to selection of vegetation for restoration from Appendix E.

(10) Read appropriate parts of Section IV for land treatment and soil conditioning measures specific to the problem soil material present at the project site.

(11) Consult Appendix D for specifications on techniques for soil stabilization after land treatment and soil conditioning measures have been completed.

(12) Consider the critical nature of the areas where problem soil materials exist. Assign a priority and decide on a level of effort and cost to be expended to restore the site.

(13) After a restoration plan has been developed and vegetation selection is completed, consult with local agricultural experts (Appendix G) for possible more up-to-date information and to discuss the plan.

(14) Implement plan.

b. Planning restoration at an existing project.

(1) Read Section III.

(2) Follow Stage 1 and Stage 2 procedures.

(3) Read Appendix C, collect soil samples, and conduct soil tests according to Figure C-1, using test procedures referenced in Table C-1.

Table I-1

Cross-Reference Index

Problem Soil Material	Occurrence and Limitations	Soil Tests	Land Treatment	Soil Conditioning	Vegetative Stabilization	Nonvegetative Stabilization	Land Use
Acid + acid-sulfate	Para 65-72 Fig. II-11 Fig. B-1 Table B-1	Pages C-1 to C-4 App. H	Para 143-175, 187-197 App. D	Para 176-197 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23
Saline - alkali	Para 73-81 Fig. II-12 Fig. B-1 Table B-1	Pages C-1 to C-3, C-5	Para 143-175, 198-209 App. D	Para 176-186, 198-209 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23
Excessively drained	Para 82-83 Fig. II-13 Fig. B-1 Table B-1	Pages C-1 to C-3, C-5	Para 143-175, 210-218 App. D	Para 176-186, 210-218 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23
Poorly drained	Para 84-87 Fig. II-14	Pages C-1 to C-3, C-6	Para 143-175, 219-230 App. D	Para 176-186, 219-230 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23
Dispersive clays	Para 88-93 Fig. II-15	Pages C-1 to C-3, C-6	Para 143-175, 231-237 App. D	Para 176-186, 231-237 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23
Wind erodible	Para 94-101 Fig. II-16	Pages C-1 to C-3, C-7	Para 143-175, 238-254 App. D	Para 176-186, 238-254 App. F	Sect. V App. E	Sect. VI App. D	Pages III-18 to III-23

restoration to those looking for specific design information. The information contained in this report can be used at various stages of project development to address the following considerations:

- Occurrence of problem soils at the project site.
- Appropriate soil tests for soil boring samples to determine the presence of problem soil material.
- Special handling of problem soil material.
- Preparation of contract specifications for project construction and operation.
- Identification of problem soil material at existing projects.
- Preparation of contract specifications for maintenance contracts for problem soil materials.
- Evaluation of contract proposals for operation and maintenance work on problem areas.

15. The report is organized to allow the user to locate particular information and concentrate on specific areas of interest as easily as possible. The Table of Contents and the Cross-Reference Index (Table I-1) provide easy access to specific information. An Index (Section VIII) allows the user to locate information on a specific aspect of restoration. References (Section VII) to the literature used to write the report are also available for the user's further consideration. A glossary (Appendix A) is provided to explain definitions and terms associated with restoration of problem soil materials as used in the report. Appendix B presents the distribution of problem soil materials by land resource areas to indicate the presence of problem soils at a project site. Appendix C presents a tabulation of methods to be used during onsite surveys. Appendix D describes in detail various soil stabilization measures and gives examples of design specification for a number of measures. Appendix E is an extensive tabulation of plant materials suited for specific problem soil materials in various locations around the country as well as specific characteristics for each species. Appendix F describes the characteristics of short-term mulches. Sources of additional information and expertise of land restoration are listed in Appendix G. The user should contact local expertise and discuss specific restoration problems to obtain the most up-to-date information that might be applied to the project. Appendix H describes in detail existing literature on methods for testing acid sulfate soils.

16. Two examples of procedures that could be followed in using this report are:

10. The information presented in this report has nationwide application and has been prepared in response to specific COE District needs. However, the report is confined to the restoration of project sites at upland locations beyond the coastal zone and at elevations at and above the riparian zone. Subjects pertaining to the revegetation of dredged material disposal sites are not addressed, even though information presented in this report may equally be applied to dredged material disposal sites.

11. A number of terms and definitions have been used elsewhere to describe land rebuilding processes. These include restoration, which is defined as a returning of the land exactly to its original condition, that is, conditions which existed prior to disturbance of the site; reclamation, which implies that the site will be habitable to organisms originally present in approximately the same composition and density after the reclamation process has been completed; and rehabilitation, which means that the disturbed site will be returned to a selected form and productivity in conformity with a specific land-use plan (Box 1978).

12. Complete restoration, as defined above, is seldom, if ever, possible and depends upon the magnitude of disturbance. Some values are often lost or severely altered. Reclamation is an acceptable and realistic alternative especially if the site is made habitable to other organisms that closely approximate the original, filling the same ecological niche. However, native species should be used where practicable and feasible (Hodder, no date, p 66). Rehabilitation efforts must be consistent with surrounding aesthetic and other values set forth in the land-use plan. The new land use should also be ecologically stable and of reasonable value to society.

13. In this report, the term land restoration as defined by Bradshaw and Chadwick (1980) is used because it provides a broader and more realistic framework than the rigid definition of restoration presented above. Thus, throughout this report the phrase "land restoration" describes all those measures designed to upgrade disturbed land so as to restore its biological potential and bring it back to some beneficial use.

Organization and Use of This Report

14. The contents of this report should be helpful to a variety of different users, ranging from those seeking to gain a general perspective on land

- To plan and design appropriate corrective actions for implementing all erosion and sediment control measures needed to stabilize degraded watershed conditions.
- To upgrade the biological potential of the stabilized conditions where expected benefits are commensurate with estimated costs.
- To prescribe restoration measures, where feasible and permissible, only for the highly critical and/or environmentally sensitive areas.

8. Under these objectives only a portion of the total restoration needs may be met within the watershed. It is recommended that a Special Land Restoration Plan be prepared, along with a written report, stating why the entire watershed/subwatershed was not restored or upgraded (Forest Service Manual 25001981; US Forest Service). Examples of the incorporation of different levels of effort in restoring problem soils are found in Section IV (paragraph 179 and Table IV-6). Examples of problem soil materials and other conditions that, from field observations alone, would be expected to require the highest restoration priority rankings are listed in Section III (p III-12).

Purpose and Scope

9. The primary purpose of this instruction report is to provide guidance to Corps of Engineers (COE) personnel and to Corps contractors in the selection of suitable and effective techniques to control soil erosion, contaminant runoff, and other long-term impacts at project sites. Appropriate information and guidance for effective land restoration have been developed and are presented. The guidance includes general considerations associated with the interaction of soils, geology, and climate in potentially difficult restoration situations. Information and techniques are presented relating to treatments for problem soil materials and construction site modifications prior to establishment of vegetation, maintenance of vegetation, and productive uses of restoration areas. The materials presented in this report are the result of the compilation, analysis, and synthesis of widely scattered information that emphasizes low-cost maintenance and long-term revegetation techniques. These techniques involve the use of native plant materials for upgrading and sustaining the biological potential of various upland problem soils within the context of wildlife, recreational, and other land uses appropriate to the mission of the Army Corps of Engineers.

occurring at the site. Selection of cost-effective restoration measures on the affected project sites requires all of the following activities:

- Recognition of the existence of problem soils at project sites during the planning and design phases of the project.
- Development of a preconstruction land restoration plan (including vegetative and nonvegetative practices that are compatible with the geologic, climatic, and soil conditions occurring after construction and with postconstruction land uses).
- Proper implementation of the land restoration plan during and following construction in accordance with assigned restoration priority rankings for specific project sites.
- Follow-up maintenance to ensure that in-place practices are functioning properly.

5. It must be recognized that the need to restore project sites is predicated on the basis of sound stewardship of our Nation's natural resources.

6. Emphasis is placed on the need for establishing restoration priority rankings for project sites. This permits the incorporation of different levels of land restoration effort into restoration plans, for the integration of the most cost-effective measures into the construction contract provisions. The minimum goals are to (a) stabilize the sites and (b) create self-sustaining ecosystems of low maintenance. The breadth and degree of sophistication of land treatment, soil conditioning, vegetative and nonvegetative stabilization, and land-use practices must be determined in relation to a battery of watershed variables, including but not limited to the following:

- The synergistic interaction of climate, geology and soils, topography, hydrology, and man-made (e.g., cultural, socioeconomic, aesthetic, sociocultural, etc.) conditions at the specific site (see Sections II and III).
- The area and classification, type of the after-the-fact construction site (see Section III).

  The area and nature of each problem soil at the project site in relation to the watershed as a whole (see Section II).
- The presence of sensitive ecosystems that could be negatively impacted, or of unique or sensitive visual resources (see Section III).
- The restoration priority ranking assigned to a specific project site by the interdisciplinary survey team.

7. As pointed out in Section III, the minimum objectives of after-the-fact restoration plans should be:

RESTORATION OF PROBLEM SOIL MATERIALS AT CORPS OF ENGINEERS CONSTRUCTION SITES

SECTION I: INTRODUCTION

1. As a constructor of major water resources facilities throughout the US, the US Army Corps of Engineers is required to build and maintain structures that disturb large acreages of land and require massive soil and rock excavation and fill construction. Construction of these Corps of Engineers projects can result in the loss of the protective cover of vegetation and the exposure of soils and subsurface geological materials to the erosive and leaching action of water and wind. Unless suitable land restoration measures are implemented, these conditions can produce both short- and long-term detrimental impacts on the land and water resources of the construction site and adjacent areas. In this report, the term land restoration means all measures used to upgrade problem soil materials at project sites and facilities in a manner that restores their biological potential.

2. The impacts of these construction activities on the site water resources result primarily from: (a) the increased sediment load created by the erosion of disturbed land and increased storm-water runoff; and (b) contaminant runoff due, for example, to exposure of pyritic, saline, alkali, and seleniferous soil materials.

3. Construction impacts on the site land resources include the loss of vegetative cover and surface soil materials, and the degradation of the water resources which together form the elements of habitat and thus influence the suitability of the site to support vegetation, woodlands, wildlife, recreation, and/or other land uses.

4. The restoration of Corps construction sites usually requires a combination of soil fertility amendments, and vegetative and structural practices that provide a suitable growth medium, shield the soil from the erosive action of water and wind, and control excessive storm-water runoff. The establishment of a long-term, low maintenance vegetative cover that is compatible with the postconstruction land use is a very difficult task at many Corps projects because of problem soil conditions. These soil conditions result not only from man's activities (construction of cuts and fills, and postconstruction land use) but also from natural conditions, both geologic and climatic,

SECTION I: INTRODUCTION

SECTION I: INTRODUCTION

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

US customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	0.40468	hectares
acres	4046.873	square metres cubic
feet	0.02831685	cubic metres cubic feet per
second	0.02831685	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
miles per hour	1.609347	kilometres per hour
millimhos per centimetre	1.0	millisiemens per centimetre
gallons per acre	0.00093	cubic decimetres per square metre
gallons per acre	9.3536	litres per hectare
gallons per square foot	40.75	cubic decimetres per square metre
gallons per square yard	4.5273	cubic decimetres per square metre
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.000112	kilograms per square metre
pounds (mass) per acre	1.121	kilograms per hectare
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (mass) per acre	0.22	kilograms per square metre
tons (mass) per acre	2.242	metric tons per hectare
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
square yards	0.8361274	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

LIST OF TABLES (Concluded)

LIST OF TABLES

LIST OF FIGURES (Concluded)

SECTION II: IDENTIFICATION OF PROBLEM SOIL ENVIRONMENTS

SECTION II: IDENTIFICATION

SECTION II: IDENTIFICATION OF PROBLEM SOIL ENVIRONMENTS

Overview

19. Land areas may be considered to be drastically disturbed if the native vegetation and animal communities have been removed and most of the topsoil lost, altered, or buried (Box 1978). These drastically disturbed sites may not completely heal themselves through normal successional processes. The process of soil rebuilding must often start with a new growth medium, usually a mixture of subsoil, rocks, and topsoil. Plants and animals that have been completely removed must be reestablished in the disturbed area. The natural process can be promoted by altering the conditions under which native plant communities may develop or by introducing new plant communities.

20. Construction activities of the US Army Corps of Engineers involve the excavation of soil materials to depths ranging from several feet to hundreds of feet.* These areas should be perceived as drastically disturbed areas which frequently represent problem soil materials with respect to achieving both short- and long-term stabilization of the area.

21. Land areas may be difficult to restore as a result of one or more physical limitations in (a) climate, (b) geology and soil characteristics, (c) topography, (d) hydrology, (e) man-made conditions, and (f) synergistic interaction among the factors. This part of the report provides a brief review of the limiting factors that determine the nature and the extent of a critical area. A number of critical areas frequently encountered on Corps construction sites are characterized by adverse soil conditions. The nature and occurrence of these problem soil materials are described in the second half of this section.

General Factors That Influence Problem Soil Environments

22. Drastically disturbed soil materials may be severely limited in nutrients and biological life. Long-term stabilization of these materials will require the restoring of nutrients and biological life in these soil materials.

---

* A table of factors for converting US customary units of measurement to metric (SI) units is presented on page xii.

23. The limitations associated with a variety of elements can result in the occurrence of, and determine the nature and extent of, a critical area. In addition, the type and extent of the limitations will influence the remedial measures chosen for restoration of the project site.

Climate

24. Precipitation is one of the more important components of climate. The mean annual precipitation in the United States varies longitudinally across the country (Figure II-1). Since soil moisture is probably the single most significant factor in successful revegetation, it can be inferred that revegetation is more difficult in the arid and semiarid Western and Southwestern United States than in the humid Eastern part of the country. Furthermore, the importance of onsite conservation of precipitated water and snow is clear in arid regions, such as in the West. Snow provides moisture for soils and plants when it melts in the spring; however, heavy runoff from melting snow can cause erosion.

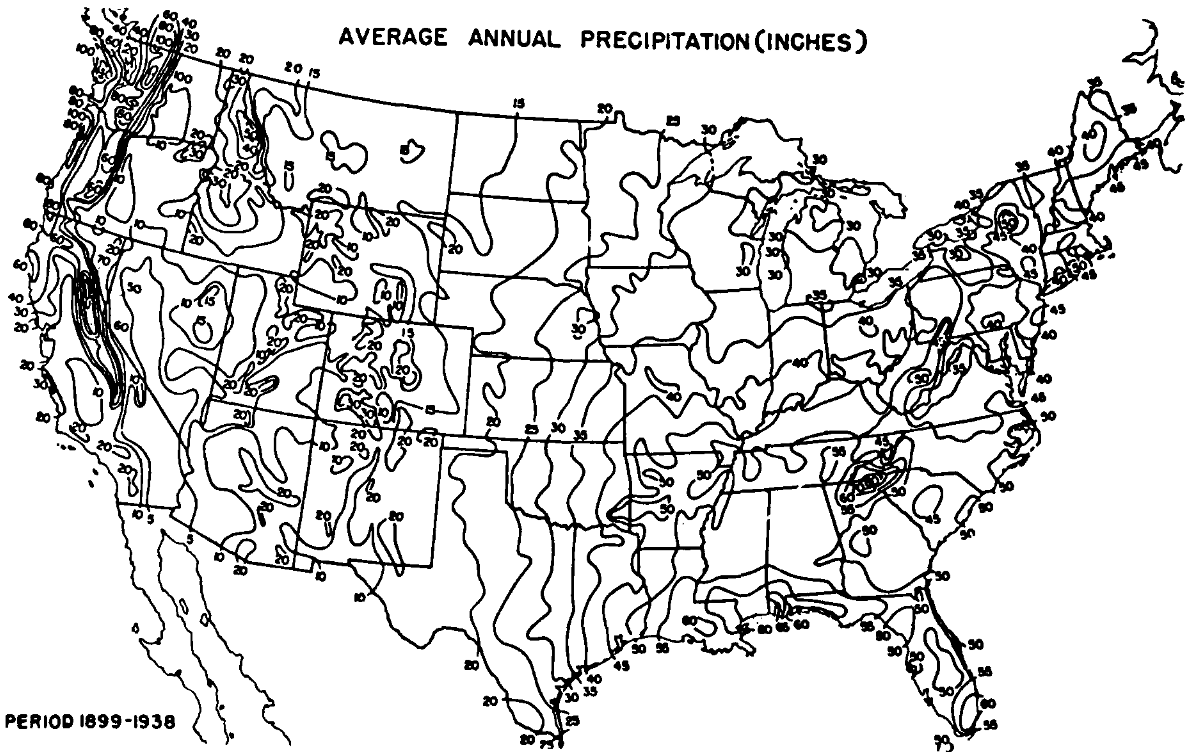


Figure II-1. Average annual precipitation of the United States
(US Department of Agriculture (USDA) 1941)

25. Annual distribution of precipitation is also an important factor. In the West rainfall is concentrated in the spring and early summer months, with individual rains being of high intensity and short duration. There is a direct relationship among effective precipitation, natural vegetation, and soil erosion. In general, low annual rainfall means more intense individual rains. The result is sparse vegetation. Intense rainfall on soils with sparse vegetation results in soil erosion (rills or gullies) and runoff with high sediment content.

26. Other climatic factors that influence critical areas are temperature, wind, humidity, solar inclination, length of growing seasons, and general seasonal variation. The average monthly temperature in the United States ranges latitudinally from north to south. The coldest average monthly temperatures are found along the United States-Canadian border and the warmest along the United States-Mexican border. Figure II-2 shows average monthly temperatures for the United States in July and January. Temperature also dictates the number of frost-free days and, consequently, the length of the growing season. Frost-free days and the length of the growing season decrease from south to north and at higher altitudes. In general, the Western United States has shorter revegetation periods than the Eastern United States because of the higher altitudes found in the West.

27. Wind velocity and direction are seasonally variable. Duration of winds is also important. In the East, topographic and vegetative barriers to wind abound, thereby reducing the intensity and duration of the wind. In the arid and semiarid West, large fetch areas occur due to the lack of vegetation and the flat topography. Strong winds can be expected for at least part of the year in all areas of the arid West. The contribution of wind to critical areas is twofold. First, in the arid regions of the country, high winds and unprotected soils create conditions conducive to dust storms. Second, warm, dry winds blowing over revegetated areas will increase the evapotranspiration rate, thus rapidly decreasing available plant moisture. Dust and evaporation problems are not as severe in the Eastern as they are in the Western United States.

28. Relative humidity is the amount of moisture, in gaseous form, contained in the atmosphere at a given temperature compared to the total amount of moisture capable of being in the atmosphere at that same temperature. The relative humidity in the Western and Southwestern United States is low and it

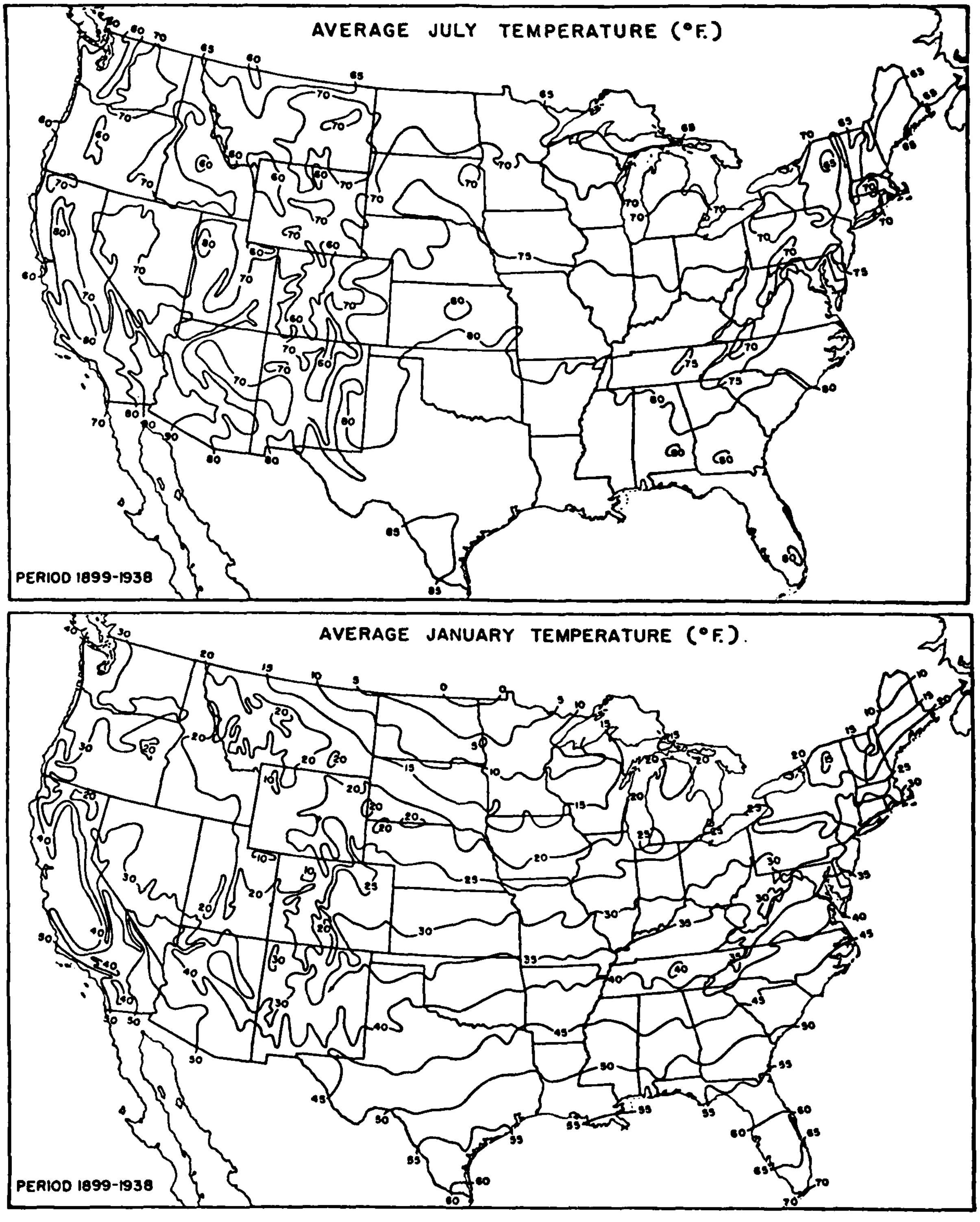


Figure II-2. Average monthly temperatures in the coterminous United States (USDA 1941)

increases gradually and uniformly toward the Northwest, Northeast, and East. Humidity closely mirrors precipitation zones because of the relationship between the two. Atmospheric moisture is relevant to area revegetation and dust generation. Hot, dry air dries out soils and plants, thereby increasing dust problems and decreasing the potential for successful revegetation.

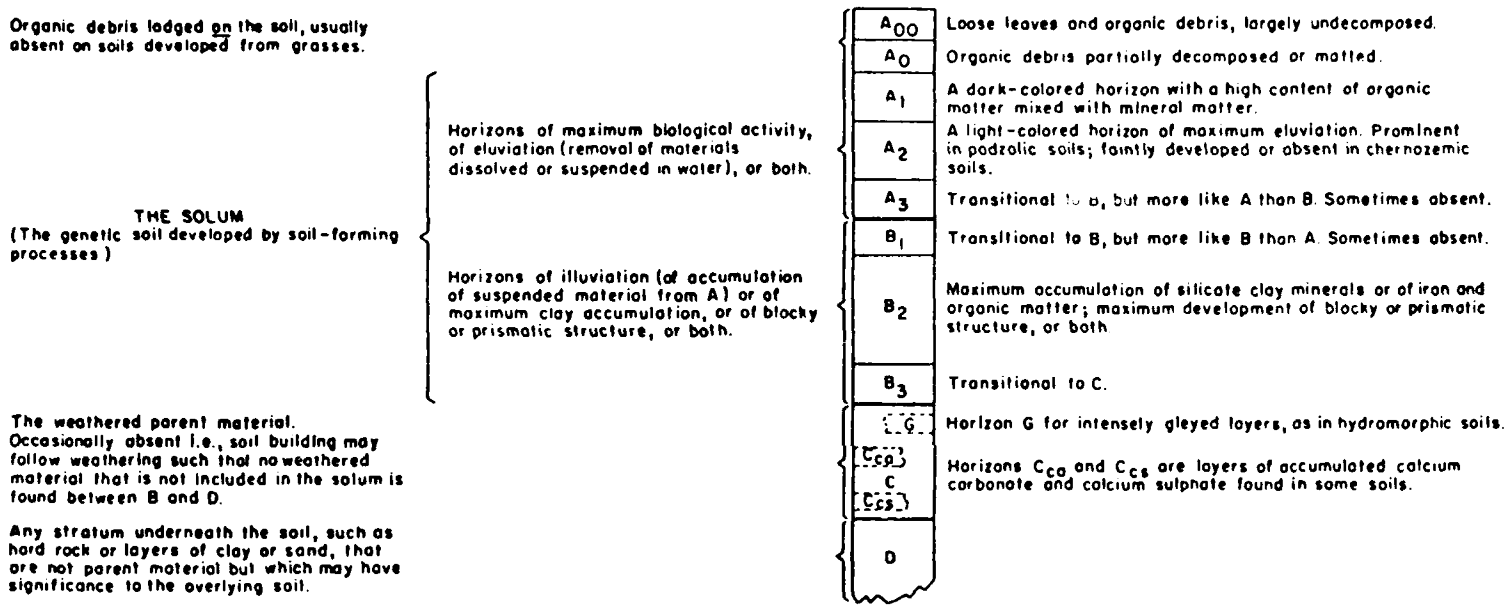
29. Solar radiation is the amount of solar energy striking the surface of the earth. Low humidity and high altitudes in the arid Western United States provide conditions where high levels of solar energy strike the earth. Solar radiation is highest in the arid West and Southwest and decreases inversely with humidity. Because plants absorb a small portion of light energy before it strikes the ground, solar radiation also affects revegetation. In the Western United States solar radiation is greatest on south-facing slopes, creating rapid evaporation of soil moisture and leaf transpiration and increasing the difficulty of revegetating slopes with south and southeast aspects.

Geology and soil characteristics

30. The soils existing at a construction site prior to disturbance are critical to the success of revegetation. Soils are formed from weathered bedrock and can either be in place immediately above the parent bedrock (residual soils) or they can be transported by water, wind, or ice and deposited elsewhere (sedimentary soils). Soils are generally characterized by three layers referred to (from top to bottom) as the A, B, and C horizons (Figure II-3). The A horizon, usually called the topsoil, is normally higher in organic matter and is subject to the leaching of soluble materials by infiltrating water. The B horizon, usually called the subsoil, is a zone of accumulated leached materials. It is usually thicker than the A horizon and has a higher clay content. The C horizon is usually called the substratum and consists of weathered bedrock and parent materials.

31. Exposed soils at project construction sites are often composed entirely of subsoils. In some cases, the upper layers of soil (A horizons) will have been removed, leaving only the B and C horizons. In other cases, soils will be excavated and disposed in another area. The A horizon may be buried under the B and C horizons. Soil material at project sites can, therefore, be severely lacking in organic matter and fertility.

32. Western soils are primarily residual soils resulting from hundreds if not thousands of years of soil formation processes. Eastern soils generally developed more quickly due to the abundance of water and dense vegetative



Horizon B may or may not have an accumulation of clay. Horizons designated as C_{ca} usually appear between B_3 and C. The G may appear directly beneath the A.

Figure II-3. Idealized soil profile (USDA 1957)

growth. Sedimentary soils of alluvial (water deposited), glacial (ice deposited), or loessial (wind deposited) origin occur in the Western United States but to a lesser degree than residual soils. Eastern soils may be residual or sedimentary but in either case are usually more heavily weathered, thicker, and have more well-developed soil horizons than Western soils.

33. Soil type is based on physical, chemical, and biological properties. Physical properties include texture, structure, compaction, and available water-holding capacity and permeability. Chemical properties include clay mineralogy, acidity, alkalinity, salinity, cation and anion exchange capacity, organic matter, and available nutrient content. The biological properties include both microorganisms and macroorganisms (animals and plants).

34. Soil texture. Soil texture is a measure of the proportion of particles in the various particle-size groups--sand, silt, and clay. These particle-size groups are determined by a mechanical analysis (Figure II-4). Once the particle-size distribution is known, the textural name of the soil can be determined from the relative percentage of each group, as shown in the textural triangle (Figure II-4). Terms commonly used to describe soil texture are listed in Table II-1.

35. Sand, when dominant, forms a coarse-textured or "light" soil that allows water to infiltrate rapidly. Silts and clays make up fine-textured or "heavy" soils, and depending upon the clay mineralogy can be quite cohesive and slow to erode. Soils that are high in silt and fine sand and low in clay and organic matter are generally the most erodible.

36. Soil structure. The structure of a soil affects the intake of air and water. Individual soil particles form into groups (aggregates) with planes of weakness between them. Although soil structure is described in terms of size and shape of aggregates for purposes of classification, other factors associated with structure are more important from the standpoint of soil hydraulic properties and soil-plant relations. These factors include (a) the pore size distribution that results from aggregation, (b) the stability or resistance to disintegration of aggregates when wet and their ability to reform while drying, and (c) the hardness of the aggregates. Organic matter often improves soil structure by serving as a binding agent for soil granules (US Environmental Protection Agency (USEPA) 1977).

37. The aggregates have properties unlike an equal mass of nonstructural soil particles. Soils that do not have aggregates with natural

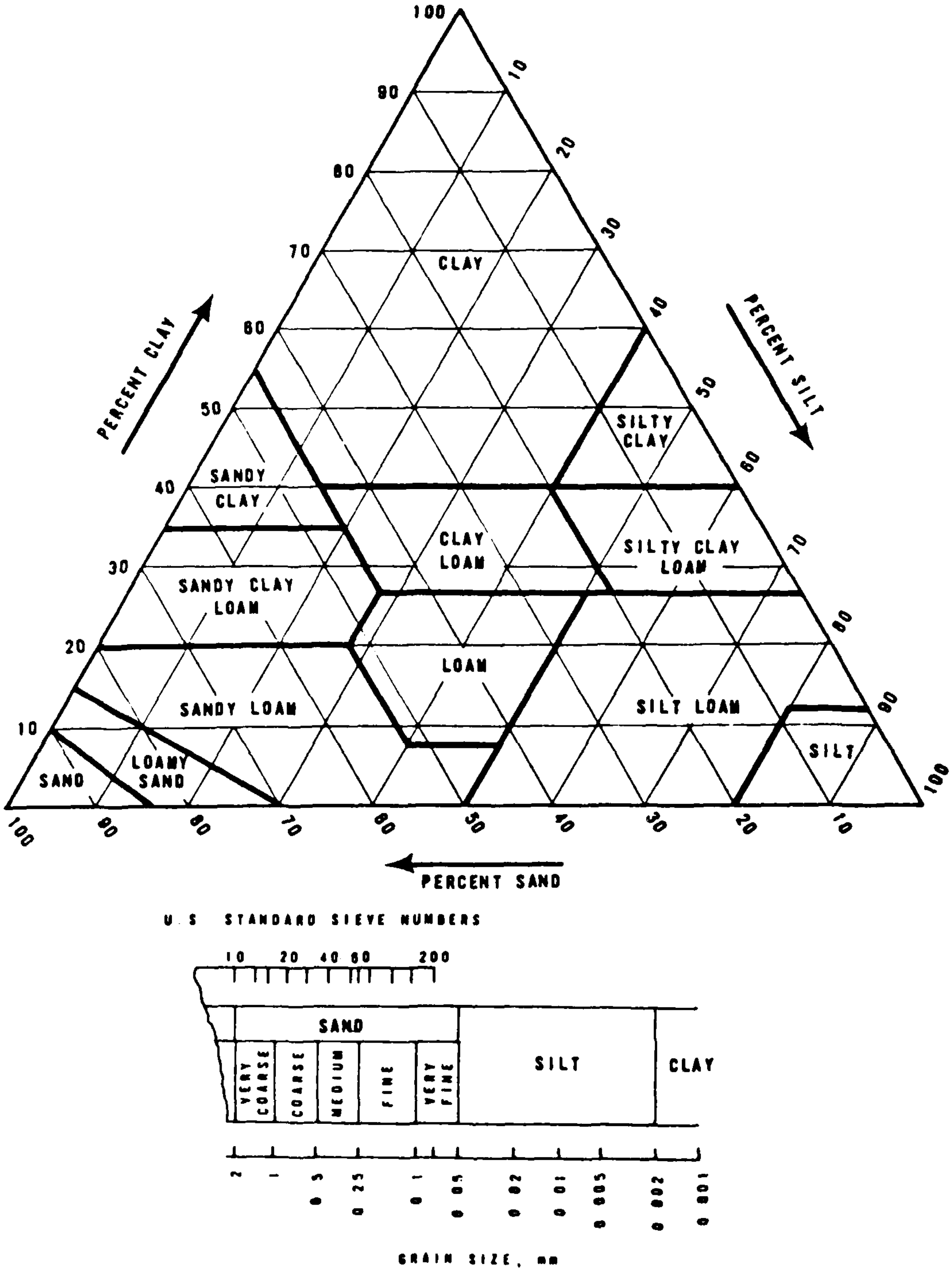


Figure II-4. Proportions of sand, silt, and clay in the basic soil-textural classes (USDA, Soil Conservation Service (SCS) 1976)

Table II-1

Soil Textural Classes and General Terminology Used in Soil Descriptions*

General Terms		Basic Soil Textural Common Class Names
Name	Texture	
Sandy soils	Coarse	Sand Loamy sand
Loamy soils	Moderately coarse	Sandy loam Fine sandy loam
	Medium	Very fine sandy loam Loam Silt loam Silt
	Moderately fine	Clay loam Sandy clay loam Silty clay loam
Clayey soils	Fine	Sandy clay Silty clay Clay

* US Environmental Protection Agency (1977).

boundaries are considered to be structureless. Two forms of structureless conditions are single-grain and massive. The single-grain condition refers to soils (such as loose sands) in which primary soil particles do not adhere to one another and are easily distinguishable. In massive soils, primary soil particles adhere closely to one another but the soil units are large, irregular, and lack planes of weakness.

38. Soil compaction. Soil compaction is the compressing of soil particles together, thereby decreasing pore space. Severe compaction has detrimental effects on plant growth because moisture, air, and plant roots are prevented from moving through the soil. Several factors can result in soil compaction including dispersive clays, silty texture, weakly developed soil structure, low organic matter, soil moisture, and pressure exerted by heavy earth-moving machinery. Problem soil materials encountered at project sites are often subsoil materials which exhibit one or more of these factors. These soil materials generally have a poor soil structure with little organic matter. The use of heavy machinery is a very common practice at project construction sites.

39. Water-holding capacity and permeability. The ability of a soil to supply water to plant roots depends on its texture, permeability, depth, and organic matter content. The available water capacity of a soil is the difference in water content between field capacity and the wilting point. Coarse-grained soils have limited capacity to hold moisture due to the rapid percolation of water. Soils that are able to hold large quantities of available water are desirable from a plant growth standpoint. Soils tend to hold more total water as either organic matter and/or clay content increases. Also, the percentage of moisture held at the wilting point (15 ATM tension) increases. Generally, soils have more water available to plants as either clay or organic content increases but the available water does not increase nearly so much as the total water held at field capacity. This is because the percentage of water held at the wilting point also increases. It should be noted that lack of aeration to plant roots rather than lack of available water to plants may cause growth problems in soils with a high clay content. Western soils frequently have a high clay content. Soil wetness also influences runoff. As the pores fill with water, the runoff rate increases because the infiltration rate has been exceeded.

40. The permeability of soil refers to the movement of water and air through it. Soils are extremely variable with regard to water transmission. Soils formed in place and by alluvial deposition may be extremely variable not only in a lateral direction but with depth as well. The heterogeneous nature in which alluvial soils are deposited adds materially to the variation in their water-transmitting properties. Alternate layers of coarse and fine sediments are commonly found in alluvial soils and usually conduct water more readily in a horizontal than a vertical direction. Soils developed under high rainfall and temperature are lower in exchangeable bases and higher in iron and aluminum oxides.

41. Clay mineralogy. Mineral components of soils (as opposed to organic content) are determined by the composition of the earth's crust from which they were derived such as igneous rock, shales, or sandstones. Elements are usually never found alone but are always in chemical compounds. Exposed minerals can cause problems in revegetation if weathering produces toxic by-products. Clay mineralogy is influenced markedly by the type and length of the weathering process.

42. Soil acidity. Soil acidity is a measurement of the hydrogen ion concentration. It is described by various terms including hydrogen ion concentration, soil reaction, or pH values. Total acidity or the quantity of a base required to raise soil pH to any selected pH value includes exchangeable hydrogen and aluminum ions and all other compounds that, upon either hydrolysis or oxidation, will produce hydrogen ions. Acid soils are rare in regions of low rainfall because leaching of bases has not been excessive. Vegetation tolerates varying degrees of soil acidity depending on the particular plant species. However, highly acidic soils will inhibit plant growth of most species.

43. Soil alkalinity. The amounts of soluble salts and exchangeable cations (calcium, magnesium, potassium, and sodium) in the soil determine its alkalinity. Alkali soils contain concentrations of soluble salts high enough to inhibit plant growth but the predominant cation is sodium (above 15 percent of the cation exchange capacity (CEC)) and the pH is above 8.5 (high concentrations of exchangeable sodium along with sodium carbonate and sodium bicarbonate). Leaching raises the soil pH (hydrolysis of the sodium compounds and the exchangeable sodium ions) and the active sodium ion disperses the soil colloids thus reducing water infiltration markedly. Soil alkalinity is a problem in the arid and semiarid regions under conditions of poor drainage associated with high rates of surface evaporation (mostly in river valleys and old lake beds).

44. Soil salinity. Saline soils contain concentrations of neutral soluble salts high enough to seriously inhibit the growth of most plants. The percentage of exchangeable sodium ions is less than 15 percent of the CEC and the soil pH is usually below 8.5. The excess soluble salts (predominantly chlorides and sulfates of calcium and magnesium) can be leached from the soil with little change is soil pH. Soluble salts decrease plant growth by increasing the osmotic pressure and soil moisture tension of the soil solution, thus reducing the amount of water available to the plants.

45. Cation exchange. Cation exchange refers to the capacity of the soil to hold exchangeable cations. These properties arise in the clay mineral and humus fractions of the soil. The amounts and proportions of various exchangeable cations present in soils influence the physical and chemical properties of soils. Cation exchange capacity influences the availability of nutrient cations for plants and soil nutrient losses due to leaching.

46. Organic matter. The organic matter in soils consists of a mixture of plant and animal residues in various stages of decomposition, of substances synthesized chemically and biologically from the breakdown products, and of microorganisms and small animals and their decomposing remains. Organic matter is a complex matrix that is the most active component of soil. It is effective in contributing to soil structure, soil permeability, cation exchange capacity, nutrient and water-holding capacity, and the biological life of a soil.

47. Nutrient content. At least 16 plant elements are considered necessary for plant growth--carbon, hydrogen, and oxygen, which are obtained from carbon dioxide and water, and nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, iron, manganese, zinc, copper, molybdenum, boron, and chlorine, which are obtained from the soil. The total quantity of an element or nutrient in the soil has little relationship to the amount available to plants since only the fraction of a nutrient that is in either the soluble or exchangeable ionic form is available for absorption by plants. According to Berg (1978), lack of plant-available nitrogen and phosphorus most frequently limits plant growth on drastically disturbed soil materials. Bradshaw and Chadwick (1980) found nitrogen to be the most limiting factor in drastically disturbed land. Low fertility can be a common important factor in each problem soil material discussed in this report. In natural soils a perpetual nutrient cycle eventually establishes over time in which nutrients are recycled within the plant-soil ecosystem (Figure II-5). In exposed subsoil materials, this nutrient cycle does not exist and will have to be established. Effective restoration requires the establishment of a nutrient cycle either through the use of legumes, the addition of organic matter, and/or the application of fertilizer.

48. Biological life. Microorganisms in association with macroorganisms are crucial for chemical and physical transformation of organic matter and inorganic compounds into forms that directly and indirectly affect soil fertility. In some cases microorganisms, such as endomycorrhizae when associated with plant roots, tend to encourage growth of certain woody species, whereas certain pathogenic forms are responsible for the destruction of other plants (Byers et al. 1938). Putrefactive bacteria, various kinds of fungi, and microscopic animals (protozoa and others) help convert plant residues into humus. Nitrogen-fixing and nodule-forming bacteria collect nitrogen from the air and

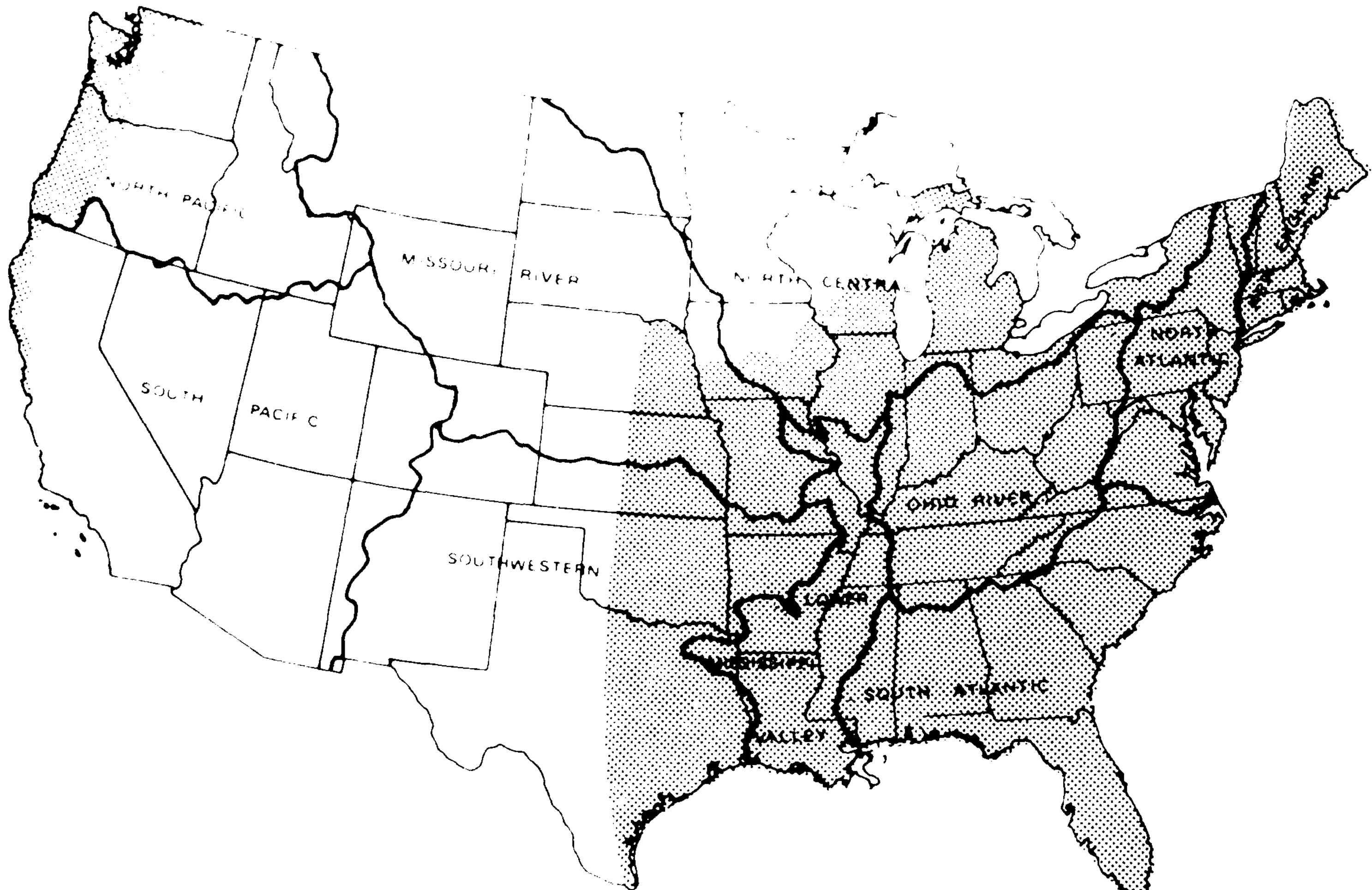


Figure II-11. Map of Corps Divisions showing potential occurrence of acid soils

c. Surface coal mining in the humid areas of the central and southern Appalachians and the Midwest has produced acid surface mine soils due to the exposure and oxidation of unweathered and unleached pyritic subsurface regolith materials. States where these problems have occurred include Pennsylvania, Maryland, Virginia, West Virginia, Ohio, Kentucky, Tennessee, Alabama, southern Illinois, Missouri, Kansas, Oklahoma, and Arkansas.

According to Mays and Bengston (1978), it is impossible to characterize adequately the extent and geographical distribution of acid surface mine soils in the humid areas of the Eastern United States because no such regional (or nationwide) compilations are available. Pyrite is the most abundant of the sulfide minerals and its occurrence is widespread in the Appalachians (Deer, Howie, and Zussman 1966) and along the eastern coast and gulf coast of the United States (Harmsen 1954; Hodges 1977).

71. The nonpyritic and in situ acid soils are reported to occur predominantly in the humid Northwestern, Southeastern, Eastern, and North Central United States, but they also exist in the humid coastal Redwood Belt of California and the humid mountains and valleys of western Washington and Oregon. They can occur anywhere in the United States where there is sufficient rainfall to create leaching conditions.

72. The parent materials underlying acidic soils are predominantly acid, but in northwestern Illinois, Iowa, Minnesota, western New York, Michigan, and Indiana, the parent materials may be cherty limestone, calcareous glacial till, and calcareous glacial drift. Associated with the latter soils are the excessively drained sands and the easily wind erodible loess and very fine sands. Figure II-11 provides a correlation of the potential occurrence of acid soils with Corps Divisions. This figure was developed from soil geological information and reports of acid soil formation following land disturbances at specific locations.

Saline and alkali soil materials

73. Definitions and limitations. Saline soils contain excessive concentrations of soluble salts. In alkali soils, more than 15 percent of the exchange complex is exchangeable sodium. Both conditions cause impaired productivity of the soil. The most common problem soils probably contain both soluble salts and high levels of exchangeable sodium.

74. Saline soil materials are quickly recognizable by the presence of a white crust on the soil surface. This crust impedes the emergence of seedlings. In general, soil materials are considered to be saline if the solution

b. With an increasing aluminum saturation of the clay complex at low pH levels, calcium, magnesium, and phosphorus become less available to plant roots. This varies with type of colloid (2:1 type clay is more affected than 1:1 type clay and the hydrated oxides of iron and aluminum, while pH and organic matter have little or no effect on ease of ionization of calcium and magnesium).

c. Unfavorable effects on the activities of nitrogen-fixing bacteria in root nodules of clover, alfalfa, and related legumes because of stresses on plant metabolism.

d. Enhanced effect on the activities of certain fungal diseases of plants.

e. Enhancement and/or control of the growth and competitive powers of different plant species.

70. Occurrence. The occurrence of potentially extremely acid soil materials is associated with geologic deposits of naturally acid strata and sulfide-bearing minerals. It should be noted that organic soils in humid regions will have pH values below 4.0 and yet support excellent vegetation. They do not contain large quantities of toxic elements (aluminum and manganese) and supply sufficient calcium and magnesium at a low pH for normal growth of plants. The following citations give some indication of the occurrence and extent of extremely acid soil materials.

a. Several areas of the Eastern coast of the United States are known to have extremely acid subsoil materials, as revealed through the exposure of pH 3.0 excavated material at various types of construction sites. Deposits of these extremely acid regolith materials remain barren for many years. The Magothy-Raritan Formation (in New Jersey) reportedly contains sulfides which when exposed are capable of generating vast quantities of sulfuric acid that persist unless neutralized with limestone (USDA, SCS 1979a). Other iron sulfide bearing minerals in the Eastern United States include marcasite, pyrrhotite, and troilite.

b. The Federal Highway Administration (Region 15) reported in 1977 that strata along a Forest Service road cut in the Cherokee National Forest (Tennessee) were characterized as pyritic and carbonaceous slates and shales, with interbeds of altered (metamorphosed) sandstones. Upon exposure of these rock types (the Anakeesta Formation) to air, rapid oxidation occurred, and red-brown stains of iron-rich precipitates and white stains of aluminum-rich precipitates were noted. Up to 10 percent of the iron sulfides in the dark shale/slate strata consisted of pyrite and pyrrhotite. Very little sulfides were found in the sandstone rock strata. The conclusion was reached that the complex geologic structure effectively prevented an accurate determination of the presence of potentially toxic materials by subsurface evaluations.

increase the availability of calcium and magnesium, thereby promoting better plant growth.

66. The phrase "potentially extremely acid or acid-sulfate" refers to soil materials containing minerals that produce acidic reactions upon oxidation. The word "potentially" refers to the possibility that any new excavating, grading, or related disturbances of the in situ soil materials may lead to the exposure and oxidation of unweathered and unleached pyritic and related subsurface regolith materials having very high residual acidity potentials upon oxidation. These minerals release sulfuric acid as a result of continuous oxidation and leaching. While conditions that produce sulfides and glauconite are similar and they frequently occur together in soils, glauconite is not a source of residual acidity. Glauconite is a hydrated aluminum silicate with varying amounts of sodium, potassium, and iron.

67. Nonpyritic acid soil materials refer to disturbed regolith soil materials on project sites that have been formed primarily through the weathering of nonpyritic sandstone, shale, and glacial till. Acid soils develop as a result of accelerated leaching of the bases (calcium, magnesium, potassium, and sodium) from the parent materials. The term "in situ soil materials" refers primarily to unexcavated, natural soils whose profiles have undergone extensive, long-term leaching in situ under humid conditions.

68. An acid soil reaction does not in itself inhibit plant growth. Rather, it is the indirect effect of increased concentrations of soluble aluminum and manganese in the soil solution that is toxic to the plant roots along with the lack of calcium, magnesium, and potassium necessary for plant growth. On the other hand, revegetation failures may occur when high application rates of limestone (pH value elevated to 6.5 and above) are used on acid soils due to the creation of iron, manganese, zinc, copper, and boron deficiencies (i.e., lime-induced chlorosis) and other related plant nutrient imbalances.

69. Indirect influences of an acid soil reaction on plant growth are notable, as follows (Truog 1938; Foy, Webb, and Jones 1981):

a. Unfavorable effects on the physical condition of clay soils when the exchangeable calcium declines so low as to limit the desired flocculation of clay crumbs or aggregates, whereupon deflocculation of the soil aggregates occurs; this leads to the downward movement within the soil profile of colloidal clays and eventually to their precipitation in the form of an impermeable hardpan or claypan.

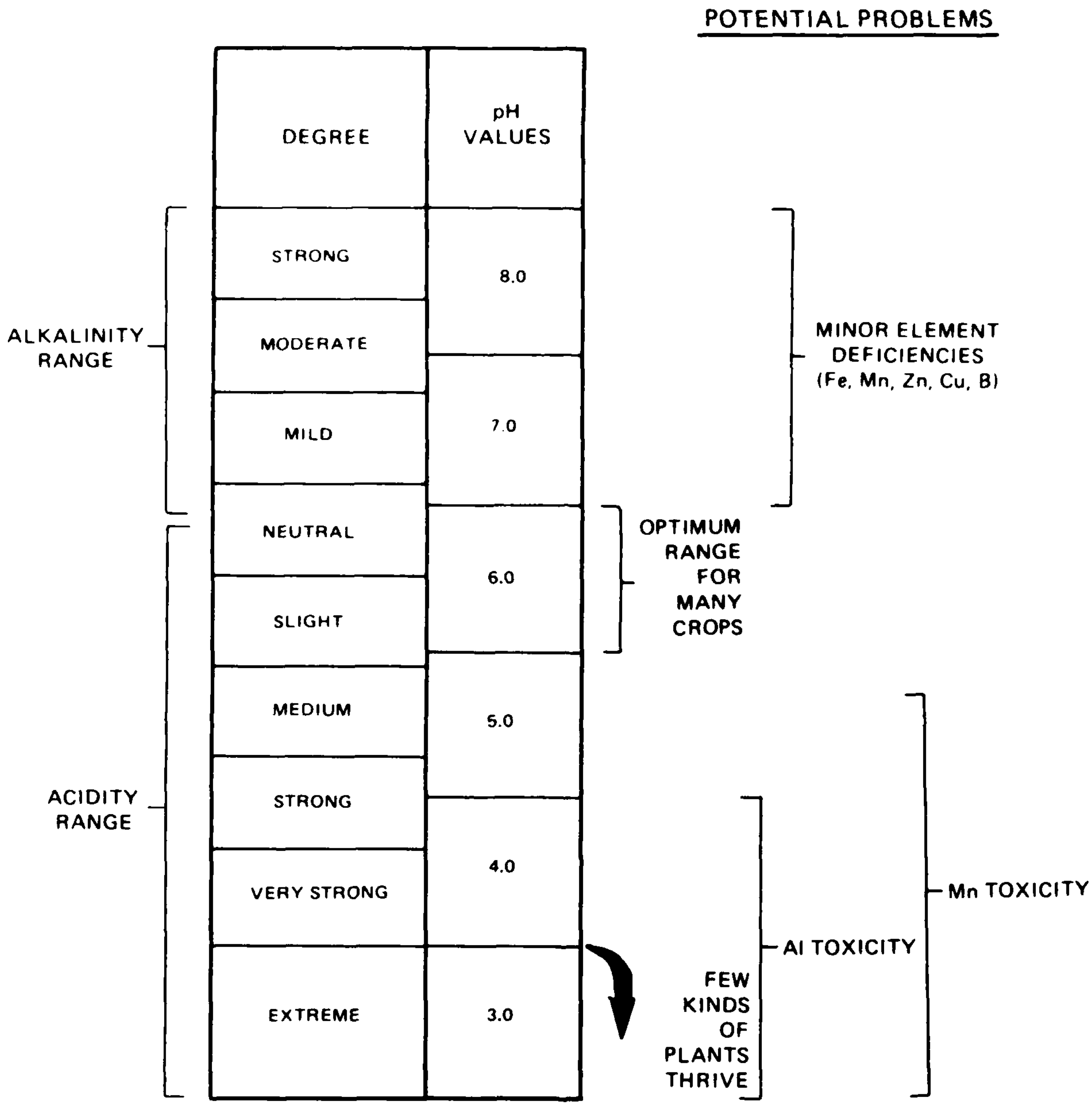


Figure II-10. pH scale (modified from USEPA 1976)

mineral soils. At and below pH 4.5, the roots of many plants may be damaged by toxic levels of aluminum and/or manganese in the soil solution coupled with a deficiency of calcium, magnesium, potassium, and phosphates. Two categories of acidic soil conditions may exist at project sites: potentially extremely acid, and nonpyritic and in situ acid materials. In either case, limestone must be applied to reduce the concentration of aluminum and/or manganese and

Table II-2

Potential Problems Encountered by Corps Districts

Location		Critical Area						
COE Division	COE District	Acid	Saline-Alkali	Excessively Drained	Poorly Drained	Dispersive Clays	Wind Erodible	Other Problems
New England		X		X	X		X	Borrow areas Slumped glacial sand deposits
North Atlantic	New York	X		X	X		X	
	Philadelphia	X		X	X		X	
	Baltimore	X		X	X		X	Hazardous waste, nonsoils
	Norfolk	X		X	X		X	
South Atlantic	Wilmington	X		X	X		X	
	Charleston	X		X	X		X	
	Savannah	X		X	X		X	Limestone sinks, seismic areas
	Jacksonville	X		X	X		X	
	Mobile	X	X	X	X		X	
North Central	St. Paul	X	X	X	X		X	
	Rock Island	X	X	X	X		X	Old sites*
	Chicago	X	X	X	X		X	
	Detroit	X	X	X	X		X	Landfills, highly organic soils
	Buffalo	X	X	X	X		X	Steep gorge areas (weathered shale)
Ohio River	Pittsburgh	X			X		X	Hazardous waste, abandoned mines, dredged material, radioactive waste
	Huntington	X			X		X	
	Louisville	X			X		X	
	Nashville	X			X	X	X	Gully control
Lower Mississippi Valley	St. Louis	X		X	X		X	Hazardous waste, wetlands
	Memphis	X		X	X	X	X	
	Vicksburg	X		X	X	X	X	Infertile soil
	New Orleans	X		X	X	X		
Missouri River	Omaha	X	X	X			X	
	Kansas City	X	X	X	X	X	X	
South-western	Albuquerque		X	X				
	Tulsa	X	X	X	X	X	X	
	Fort Worth	X	X	X	X	X	X	Borrow areas, infertile soils
	Galveston	X	X	X	X	X	X	
	Little Rock	X	X	X	X	X	X	
North Pacific	Seattle	X			X			Sterile ash
	Portland	X	X	X	X		X	
	Walla Walla		X	X			X	Borrow areas, landfills, wetlands, rock outcrops
South Pacific	Sacramento		X	X			X	
	San Francisco		X	X			X	
	Los Angeles		X	X			X	

* Landfills, abandoned mines, dredged material, slag, sand dunes, and lake beaches.

63. The various elements and their limitations discussed in the preceding pages interact to produce a wide variety of problem sites at Corps construction sites throughout the United States. The remainder of this report, while providing general guidance on the identification and restoration of these problem conditions, focuses on the major types of problem soil materials which are commonly and frequently encountered by Corps construction activities.

Description of Selected Problem Soil Materials

64. A definition and description of the general characteristics are provided for each of the following six problem soil materials:

- Acid.
- Saline-alkali (or saline-sodic).
- Excessively drained.
- Poorly drained.
- Dispersive clays.
- Wind erodible.

Characteristics of each problem soil material dictate the type of remedies needed for successful revegetation and stabilization of the site. The geographic location of these problem soil materials has been determined using the soil and regolith characteristics that describe the Soil Conservation Service's major land resource areas. Appendix B includes a detailed description of the occurrence of each problem soil material according to soils found in these major land resources areas. Additionally, documents of the occurrence of certain problem soil materials provide further evidence of where they might be encountered. Characteristics of soils on all project sites are unknown at present. Table II-2 shows a partial listing of the types of potential problems reported by various Corps District Offices. For each problem soil, a map is presented showing the correlation of the occurrence of that soil with Corps Divisions. The following discussion will define the six conditions and their limitations.

Acid soil materials

65. Definition and limitations. Acidic conditions are present when a soil material has a pH of less than 7.0 (see Figure II-10). There are few higher plants that can tolerate a soil reaction lower than a pH of 4.0 in

- Frost-free days are fewer.
- Water availability is lower.

59. Slope aspect is also an important topographic element related to revegetation. It affects day length, solar radiation loads, soil temperature, and growing season length. In the arid Western United States, south- and southeast-facing slopes undergo more evaporation than north-facing slopes due to direct solar exposure. Revegetation on south-facing slopes is more difficult because of high soil temperatures and water loss through evaporation. In the Eastern United States, evaporation of surface and soil moisture is a less serious problem, thus reducing the importance of slope aspect. North-facing slopes retain more soil moisture and are generally more densely vegetated in their undisturbed state.

60. Soil erosion is related to topography in the sense that steep slopes encourage erosion. Flat terrain would be less conducive to erosion therefore than hilly terrain, if slope steepness were the only criterion. As slope steepness increases, there is a corresponding rise in the velocity of surface water runoff, which in turn results in greater erosion. Long, unbroken slopes allow surface runoff to build up and concentrate in narrow channels, producing rill and gully erosion. Long slopes even in gently sloping terrain will erode easily. If slope steepness is doubled, the potential soil loss is approximately tripled. If slope length is doubled, the potential soil loss will be approximately one and one-half times as great. Wind erosion is a greater problem on long slopes facing the dominant wind direction than on short slopes facing the same way. It should be remembered, however, that the physical and chemical characteristics of the soil, vegetative cover, and amount and intensity of rainfall are also important in determining erosion potential.

61. Microtopography is the small-scale relief of the ground surface. Depressions create a situation that can be either an asset or a detriment to revegetation efforts. Conservation of soil moisture and protection of seeds and seedlings aid revegetation efforts. But, depressions can produce waterlogged soils or receive soluble salts and acids from the more elevated locations, and become extremely difficult to revegetate.

62. The aesthetics of a critical site are greatly dependent on topography. Topographic barriers (depressions or high ridges) can impede wildlife movement and migration.

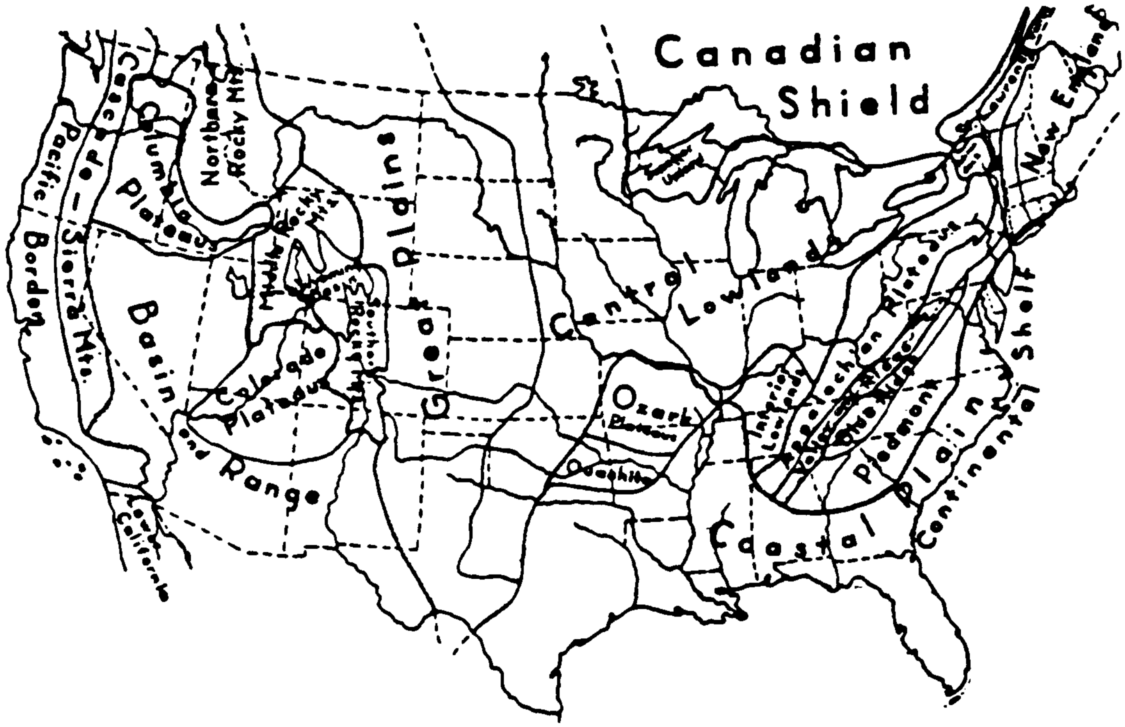


Figure II-9. Topographic provinces of the United States

Rocky Mountain region is characterized by steep slopes and jagged, mountainous peaks. Eastern areas vary from mountains or hilly regions to flat coastal plains.

57. The elevation of most Western critical sites is higher than Eastern site elevations. The Western United States has elevations ranging from 2000 to 8000 ft above sea level (excluding high peaks and low valleys) whereas the Eastern United States ranges in elevation from 0 to 2000 ft above sea level.

58. The effects of elevation on revegetation are for the most part disadvantageous. High elevation affects plant growth in the following ways:

- High elevation ecosystems are more fragile and more delicately balanced than low elevation ecosystems, thus making them more susceptible to long-term damage when disturbed.
- The length of time for plant recovery is significantly greater than in lower elevations.
- Solar radiation is greater.
- Temperatures are cooler.
- Winds are higher.
- The growing season is shorter.

heavily relied on as a water supply in the West because surface supplies are limited and overallocated. Shallow ground water aquifers typically have a low rate of flow and are mostly used for stock watering and domestic purposes. High water tables and/or perched water tables can occur seasonally in humid areas. A perched water table is a water-bearing layer which is separated from the main water table by an intervening impermeable, confining layer (see Figure II-8). Forested and cultivated soils often have subsurface layers of consolidated material called "hardpans," which inhibit the downward movement of water.

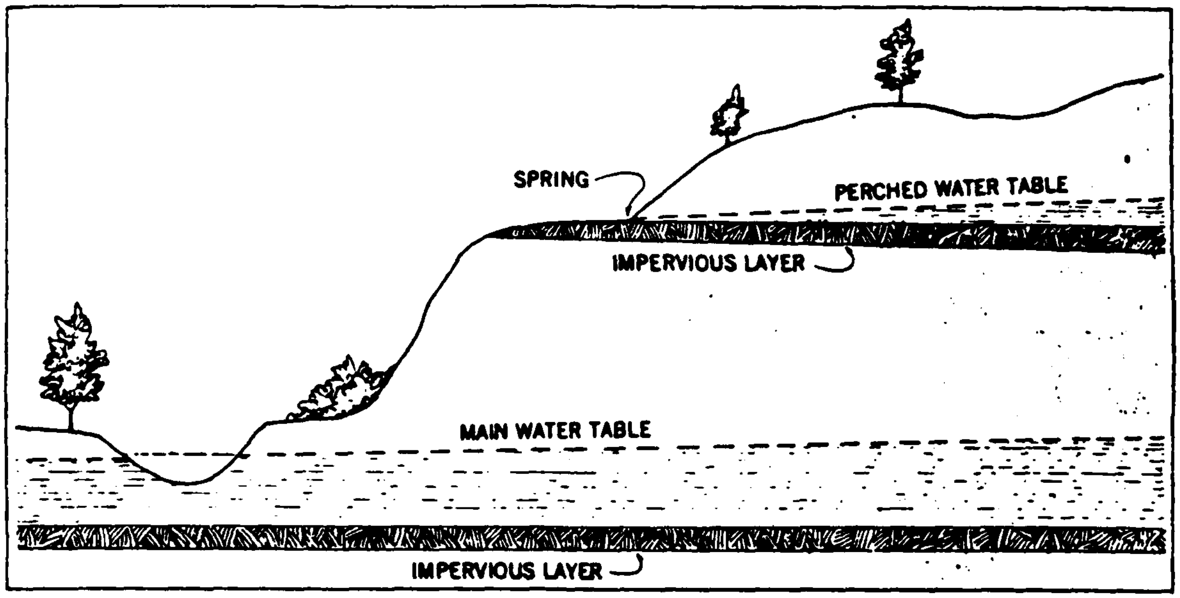


Figure II-8. Illustration showing a perched water table and its relation to the main water table (USDA 1955)

Topography

56. Topography is the shape of the earth's surface and is referred to as physiography, geomorphology, landscape, and terrain. It is discussed in terms of texture, form, geometry, elevation, slope, and slope aspect. The topography of the earth's surface is controlled by the nature of the underlying bedrock and the erosional and depositional history of the area (e.g., a flat-lying, homogeneous shale will invariably create flat surface topography). Figure II-9 shows the major topographic provinces of the coterminous United States. In general, the topography of the arid Western United States is flat to gently rolling plains interspersed with large plateaus and basins. The

2 to 5 in. or less in the arid and semiarid areas of the West and Southwest. Some parts of the Rocky Mountains (and other mountainous Western areas) have higher runoff than the surrounding plains and plateaus due to snowpack, steep slopes, and greater precipitation.

52. Moisture can evaporate from three different sources: bodies of surface water, plants (transpiration), and soil moisture (not to be confused with ground water). Ground water, for this discussion, is water stored in unconsolidated or consolidated aquifers below the water table. The combination of low humidity and warm, dry winds in the arid West leads to high rates of evaporation and transpiration of soil moisture. In fact, some climatologists define aridity as a climatic condition where more water is capable of being evaporated into the atmosphere than actually precipitates from the atmosphere. In the humid Eastern region, precipitation exceeds the rate of evaporation thus leading to the evolution of mesophytic vegetation. In the arid West, plants have evolved adaptive mechanisms typical of xerophytic vegetation for tolerating drought and salinity.

53. Soil moisture can be depleted by both transpiration from plant leaves and direct evaporation from the soil surface. The combined process is called evapotranspiration. In the arid West all available soil moisture is usually gone before the end of the growing season. Thus, irrigation is necessary in the establishment of vegetation. Irrigation is seldom used on critical area revegetation sites in the East.

54. Surface water flow (rivers and streams) can be either intermittent (flowing during the wet part of the year only) or perennial (flowing all year). Many Western streams are intermittent. The quality of Western surface flow is affected by naturally high sediment load and high concentrations of dissolved solids such as salts of sulfate and bicarbonate. Concentrations of sodium, calcium, and magnesium may also be high. These combine with chloride, sulfate, and bicarbonate ions to form salts, which could increase the alkalinity of the surface water. Eastern surface flow is predominated by perennial streams with water quality affected also by suspended solids (but to a lesser degree than in the West), acidic conditions, and iron content.

55. Ground water occurs in aquifers. Aquifers can be unconsolidated (such as glacial deposits, alluvial valley aquifers) or consolidated (such as overburden and mineral resource aquifers). Depth to ground water is the most common index to the adequacy of drainage. Ground water from deep wells is

is rapidly being pumped and depleted. In the present context, hydrology is the study of what happens to water after it is precipitated (Figure II-7).

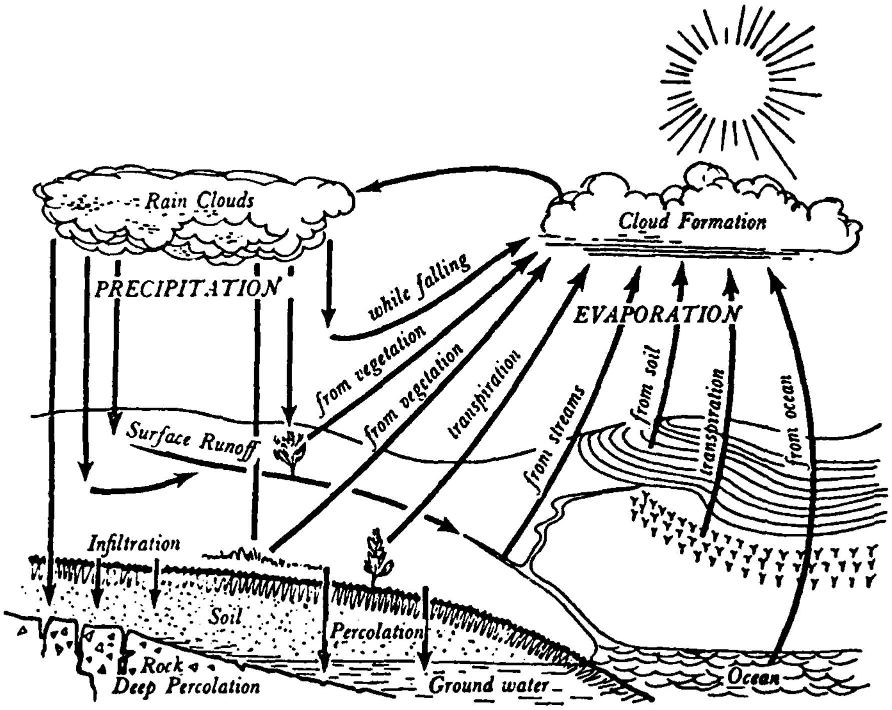


Figure II-7. The hydrologic cycle (USDA 1955)

Some of the important hydrologic factors are:

- Infiltration versus runoff.
- Soil moisture.
- Quantity and quality of surface water.
- Quantity and quality of ground water.
- Evapotranspiration.

50. In the Western United States, infiltration is generally lower than in the East and runoff is greater. The land surface in the West is sparsely vegetated and soil surfaces are sometimes sealed over due to the presence of sodium-saturated clays. Soil particles are surrounded by a layer of air, and rainfall is of high intensity and short duration. All these factors inhibit infiltration and promote runoff. In the Eastern United States, thick vegetative cover and favorable soil texture characteristics allo' infall to infiltrate the surface and thus reduce runoff.

51. The average annual runoff in the coterminous United States is 5 to 30 in. in the humid Eastern region, 40 in. or more in the humid Northwest, and

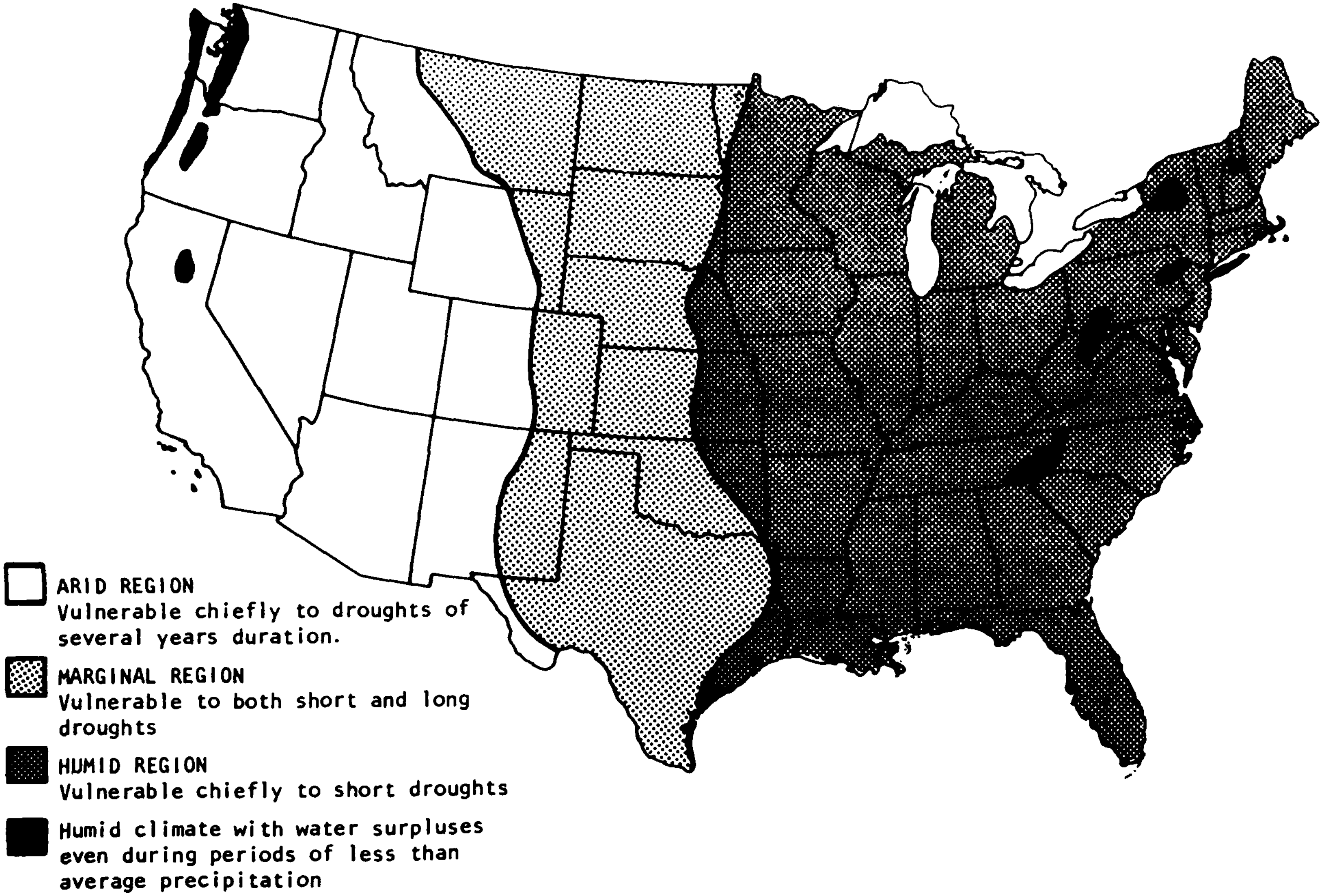


Figure II-6. Drought vulnerability in the coterminous United States

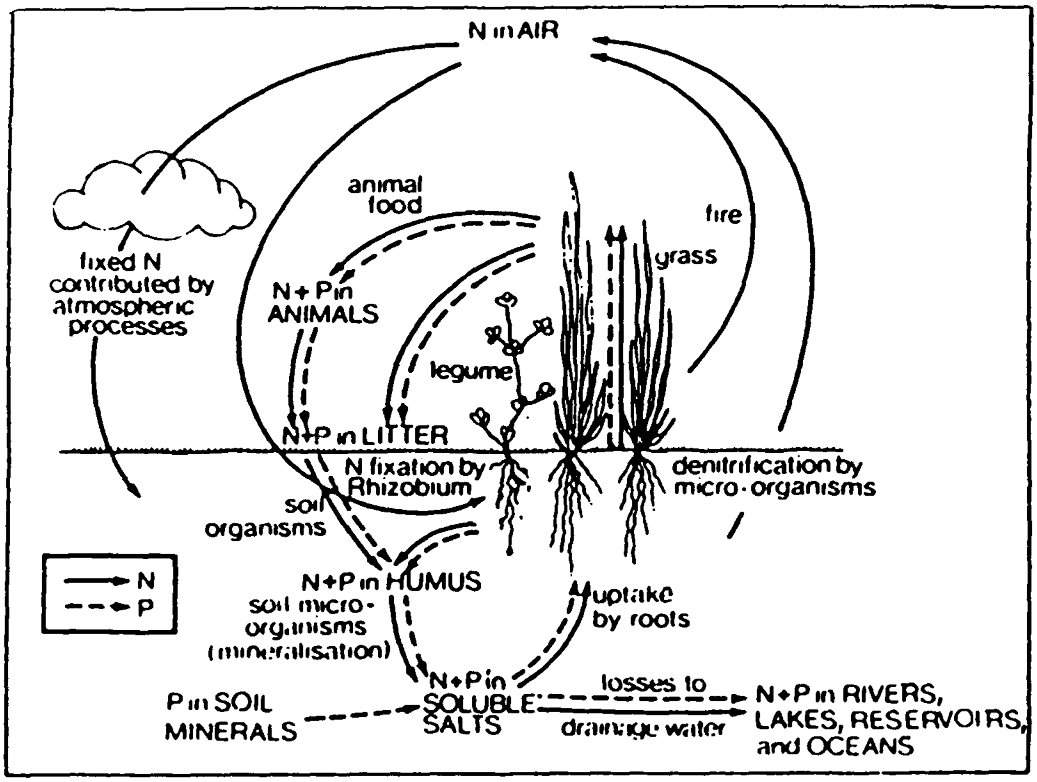


Figure II-5. Nutrient cycles through the soil-plant system (after Bradshaw and Chadwick 1980)

fix it in plant roots in a form that can be used by higher plants. Macro-organisms such as earthworms and insects furnish organic matter to the soil and bring plant nutrients up from the lower layers. Earthworms feed on organic matter and mix the soils in which they live. One of the indicators of potentially productive soils is the presence of a large number of healthy earthworms, although in productive soils of arid regions, the moisture is frequently insufficient for earthworms to exist (Byers et al. 1938). Burrowing animals also aid in soil mixing and in supplying a certain amount of subsoil material to surface horizons. Their holes form open channels which carry air and rainwater into the deeper soil layers.

Hydrology

49. In the arid parts of the country, the total water supply and the management of that supply are extremely critical. This is not to say that water management is not important in the Eastern United States, but the Western United States does experience more water shortages (Figure II-6). In the West, surface water supplies are scarce and ground water of acceptable quality

extracted from a saturated soil paste has an electrical conductivity value of 4 mmhos/cm or more, or if the dry weight percentage of soluble salt in the soil exceeds 0.1 percent and the exchangeable sodium percentage (ESP) is less than 15.

75. Soil materials are considered to be alkali (or sodic) if the degree of saturation of the clay complex with ESP exceeds 15 percent. In Australia, soils are considered sodic when the ESP is between 6 and 9 percent (Northcote and Skene 1972). These soils can disperse and affect plant growth. Soils are considered strongly sodic when ESP values exceed 15 percent. Alkali soils are divided into saline-alkali and nonsaline-alkali soil materials (US Salinity Laboratory Staff 1954).

76. The term "saline-alkali soil" refers to materials in which the solution extracted from a saturated soil paste has an electrical conductivity value of 4 mmhos/cm or more at 25° C and the ESP is greater than 15. So long as the soluble salt content remains above 4 mmhos/cm, the appearance and properties of saline-alkali soils are generally similar to those of saline or white alkali soils. The pH readings seldom exceed 8.5.

77. The term "nonsaline-alkali soil" refers to materials in which the soil solution extracted from a saturated soil paste has an electrical conductivity value below 4 mmhos/cm at 25° C, and the ESP exceeds 15. The leaching of soluble salts from saline-alkali soils results in nonsaline-alkali soils, also known as slick spots or black alkali soils. The pH readings of black alkali soils usually range between 8.5 and 10. As the proportion of exchangeable sodium increases, the soil clays and organic materials tend to disaggregate, disperse, and migrate in several directions. For example, dispersed and dissolved organic matter present in the highly alkaline soil solution may be deposited on the soil surface by evaporation, thereby causing surface darkening and giving rise to the black alkali condition. On the other hand, the dispersed clays migrate downward and accumulate to form a dense layer that is characteristically impermeable to water and air and develops a columnar or prismatic structure (US Salinity Laboratory Staff 1954).

78. Salinity directly affects plant growth through (a) the total soil moisture stress which is the sum of the soil moisture tension and the osmotic pressure of the soil solution, (b) the prevention of physiological processes that require water, and (c) the phytotoxicity due to high concentrations of boron and other ions. This condition is in contrast to the black alkali

(sodic) soil materials which affect plant growth indirectly (US Salinity Laboratory Staff 1954; Merrill et al. 1980). For example, the presence of appreciable amounts of exchangeable sodium on soil clays will disperse and puddle the soil aggregates, thereby causing poor soil aeration and low water availability to plant roots. Furthermore, if the exchange complex becomes more than 40 to 50 percent saturated with sodium, calcium is either physically removed from the root tissues or its absorption is blocked. The plant dies because of a calcium deficiency and/or competitive inhibition of calcium absorption by excess sodium ions (US Salinity Laboratory Staff 1954).

79. Salinity generally is not a problem on upland areas of the humid regions. Soluble salts originally present in, and/or released via accelerated weathering of the excavated materials are leached away, carried downward into the ground water, or carried laterally into surface waters ultimately reaching the oceans. In the arid and semiarid regions, however, salinity is more severe. In these regions, the higher evaporation and transpiration rates lead to high salt levels in the rooting medium and to osmotic pressure deficits that impede the absorption of water by plant roots. Other causes of severe salinity in these regions are limited leaching, limited overland flows of rainwater, restricted internal drainage due to a clay or silica hardpan, and high ground water tables (US Salinity Laboratory Staff 1954).

80. Occurrence. Figure II-12 shows the correlation between the potential occurrence of saline-alkali soils and Corps Divisions. Saline parent materials of marine origin are typified by the Mancos shales occurring in Colorado, Wyoming, and Utah (US Salinity Laboratory Staff 1954).

81. Two broad types of naturally occurring alkaline soil materials (i.e., pH > 7.5) occur in the United States; these are the sodic materials of arid and semiarid regions, and the calcareous materials (i.e., marl, soft limestone, and alkaline earth carbonates).

Excessively drained soil materials

82. Definitions and limitations. Soil materials with excessive internal drainage have rapid permeability to water and air. Textures range from coarse to fine sands, with particle sizes ranging from about 0.1 to 3 mm in diameter. Characteristically, these materials possess a low percentage of clay, organic matter, and CEC. Methods for measuring these properties are given in Page, Miller, and Keeney (1982). Soil materials with excessive internal water and air drainage and low CEC are, by definition, the first to dry

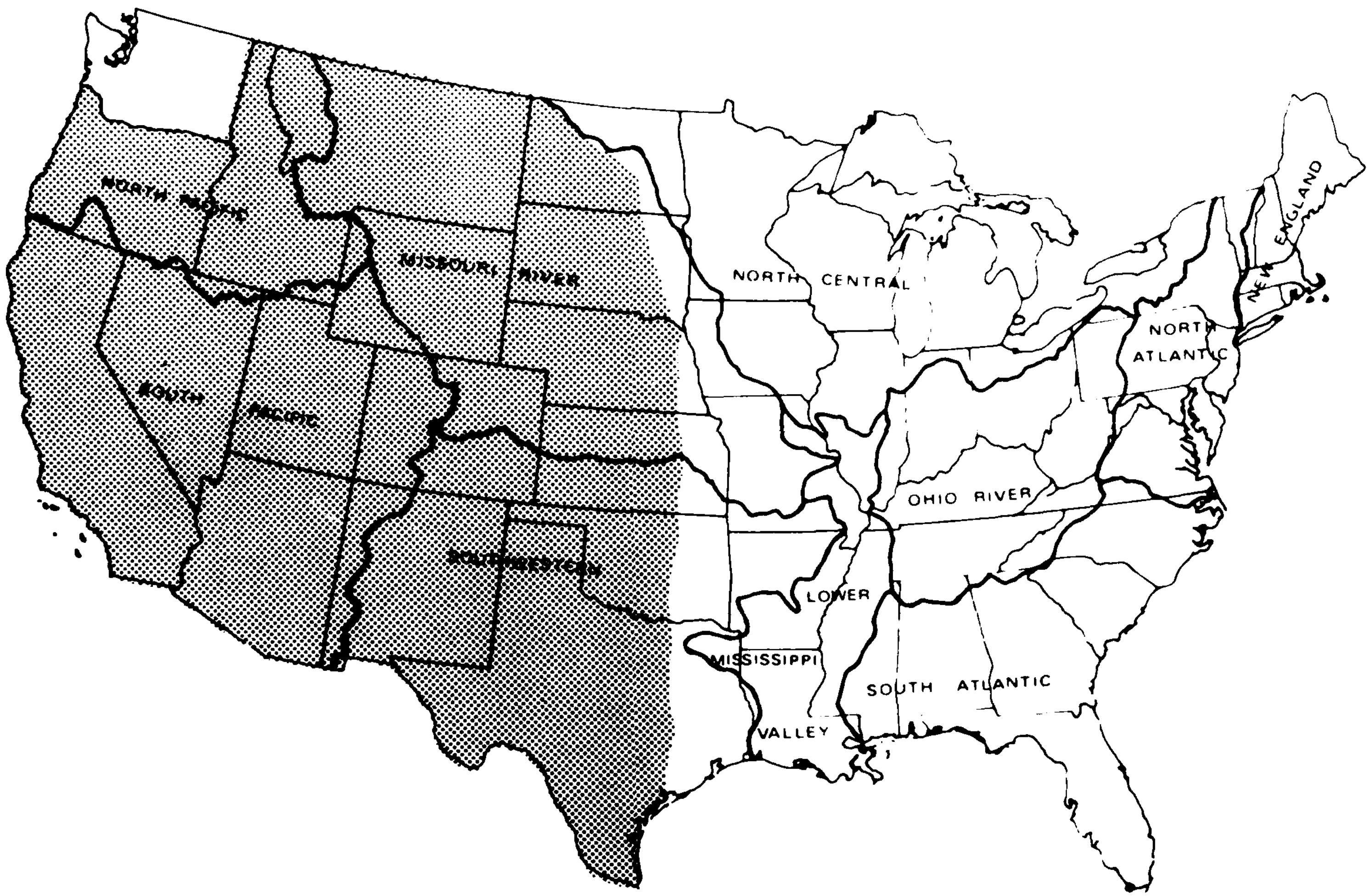


Figure II-12. Potential occurrence of saline-alkali soils

out during a drought, the first to warm up in the early spring, and the first to become depleted of plant nutrients, with or without the presence of a vegetative cover. These soils are subject to wind erosion by saltation (jumping across dry land surfaces) and surface creep. Special problems may arise for the acid and the phosphatic sands of south-central Florida, and the wind erodible sands of the Great Plains, northern Coastal Plain, and the Nebraska Sand Hills areas.

83. Occurrence. Soil materials in this group consist of the deep, surficial, unconsolidated sands having rapid internal drainage. Figure II-13 provides a correlation of the potential occurrence of these soils and Corps Divisions. They occur throughout the arid, semiarid, and humid regions, mainly in relatively small areas (Austin 1965). In Oregon and Washington, these materials occur in pumice and glacial till of the Cascade Mountains, and on sandy terraces of the Columbia River Basin. Between Cantro, Calif., and Yuma, Ariz., there are localized sand dune areas. Similar sand dunes occur in the sandhills of central and western Nebraska, North Dakota, South Dakota, and Colorado. In the Eastern United States, these materials are conspicuous in a belt extending from near Columbus, Ga., through South Carolina to Sanford, N.C. Figure II-13 also incorporates reports of the occurrence of excessively drained soils following land disturbances.

Poorly drained soil materials

84. Definitions and limitations. Upland soil materials with poor internal drainage characteristically contain excess water for varying time periods as a result of the decreased water-transmitting properties of the surface and subsurface strata. Methods for recognizing these properties are given in US Salinity Laboratory Staff (1954). Soil materials with poor internal drainage are typified as being the slowest to warm up in the spring. They are overcompacted when subjected to the passage of heavy machinery. They are also the first to become depleted of oxygen (soil anaerobiosis) when saturated with water, the first to develop a reducing soil environment which favors the growth of anaerobic bacteria, the first to produce phytotoxic organic compounds, and the most likely to inflict severe damage to plant root systems that have a high oxygen requirement.

85. From the standpoint of internal drainage (horizontal as well as vertical), the properties of the soil materials below the water table are of great importance. The soil materials near the surface may exhibit entirely

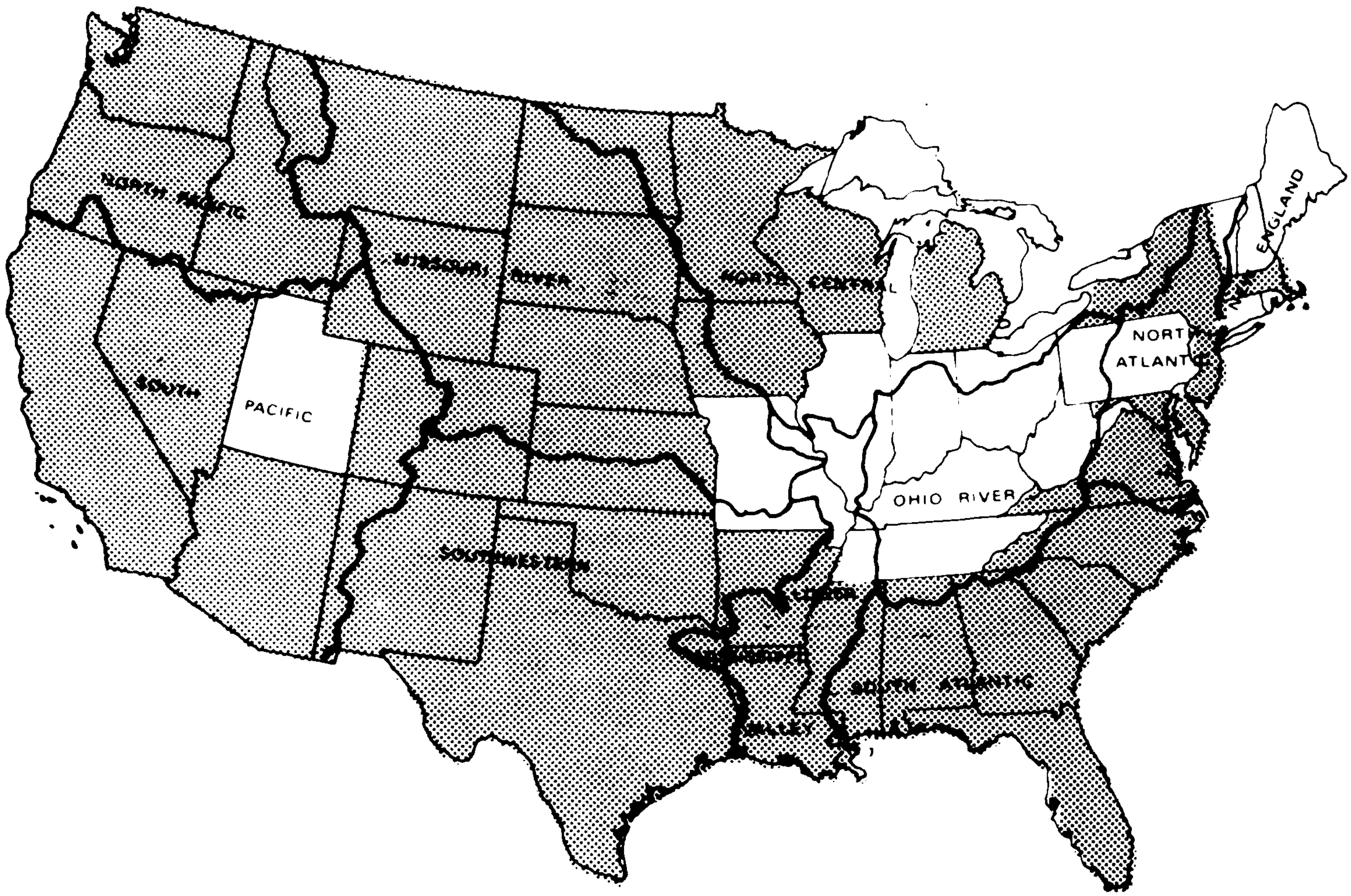


Figure II-13. Potential occurrence of excessively drained soils
(No data were found on excessively drained soils in Utah)

different water-transmitting properties than those of similar texture located below the water table (US Salinity Laboratory Staff 1954).

86. Occurrence. Soil materials exhibiting waterlogging can be expected to occur in humid regions where the subsurface strata have been severely compacted by heavy-gauge earth-moving equipment. An important complicating factor is the physical relief of the site. For example, soil materials in low spots will receive more water than soils in high spots, and formerly poorly drained soils will exhibit markedly different chemical, physical, and biological properties compared with the well-drained soil materials. Thus, over a period of time, the waterlogged and poorly drained areas on project sites may develop incipient claypans, depending on the climate, type of surficial materials, microbial action, and time.

87. The compacted layers in excavated material disposal sites are often created between the layers of distinctly different types of soil materials that are laid down in a random fashion. Generally clay loams and silty clays are most likely to be compacted by heavy machinery use during construction work. The most common index of the adequacy of internal drainage is the depth of the water table. A thorough investigation of drainage problems requires information on the hydrology, meteorology, topography, geology, and soils. Figure II-14 correlates the potential occurrence of these soils with the Corps Divisions.

Dispersive soil materials

88. Definition and limitations. Dispersive soils contain soil aggregates whose clay minerals have high exchangeable sodium. When placed in pure water, these aggregates easily disperse or deflocculate even in quiet water (Decker and Dunnigan 1976). In the natural state, these soils puddle or run together when wetted by pure water (especially the nonsaline-alkali soils) and exhibit a very low permeability to water. Upon drying, these soils shrink severely, forming cracks, pipes, jugs, and crevices. Methods for recognizing these properties are given in Decker and Dunnigan (1976).

89. The mineralogy and chemistry (amount of exchangeable sodium in the clay lattice) of the clay, and the dissolved salts in the soil pore water and in the eroding water are the factors which control the dispersiveness of clay soil materials. Dispersive clay soil materials are reported to be more easily erodible when the silt plus clay fraction exceeds 15 percent (i.e., particles finer than 0.05 mm in diameter) and when the exchangeable sodium is high

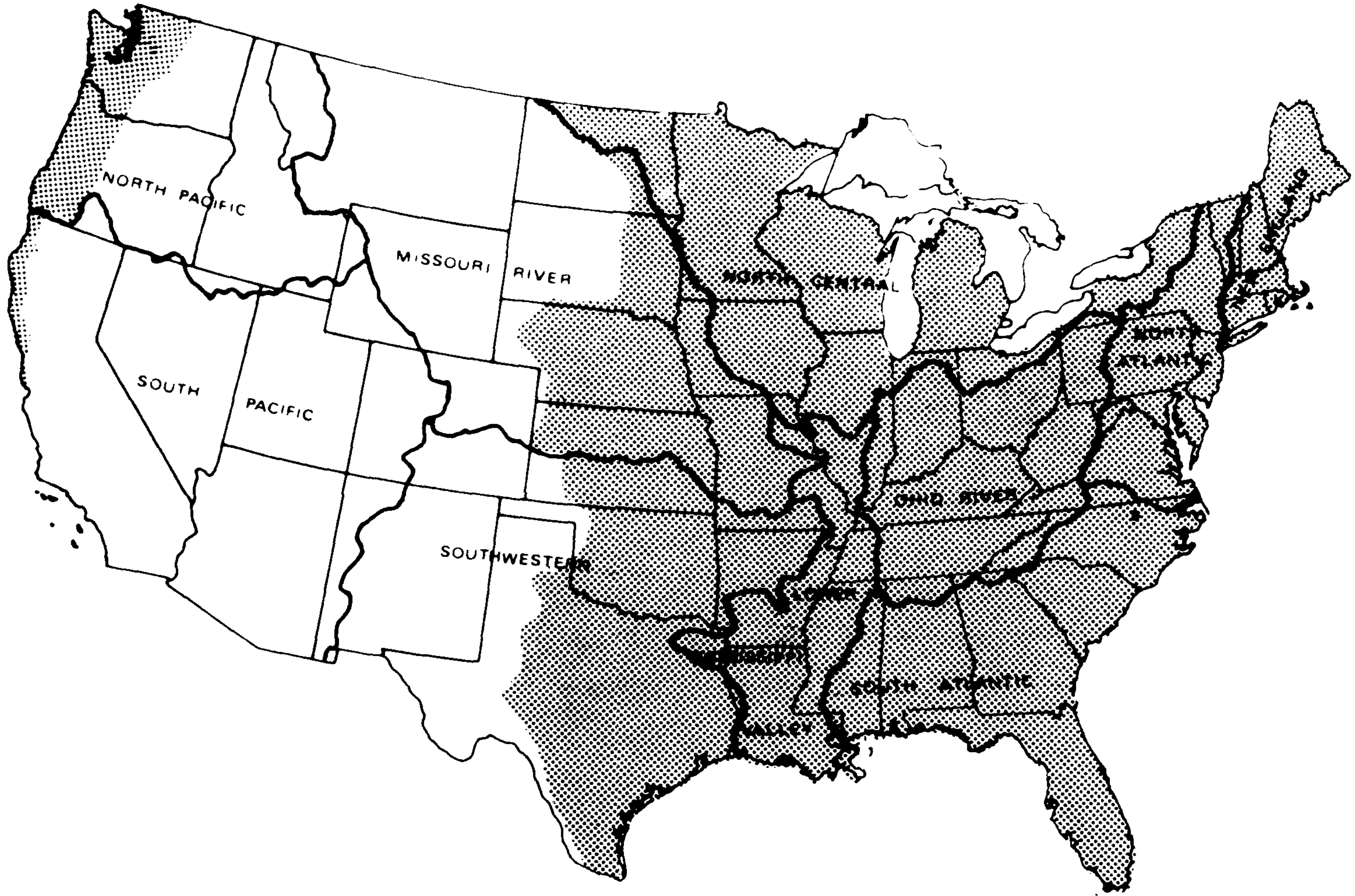


Figure II-14. Occurrence of poorly drained soils

(Decker and Dunnigan 1976). If the soils on the excavated slopes of a given site exhibit deep gullies, piping, and/or jugging, the soil materials are in the dispersed state.

90. Dispersive soil materials are notorious for their lack of easily recognizable features. Conventional engineering measurements such as Atterberg limits cannot be depended upon to reveal an innate tendency of soils to be dispersive. According to Heinzen and Arulanandan (1977), "...the rotating cylinder and flume tests, using loss of weight as a measure of erosion, provides accurate determinations of the critical shear stress of undisturbed or remolded specimens of cohesive soils."

91. Occurrence. Dispersive clay soil materials appear to occupy relatively small spots of a small percentage of the total area of most project sites. Nevertheless, these materials could be found anywhere (Sherard and Decker 1976). Figure II-15 correlates the potential occurrence of these soils with the Corps Divisions. The determination of the occurrence and extent of suspected dispersive clay soils in a given geographic area can be established best through the application of a variety of special tests on many sample specimens. Standard engineering tests on fine-grained soils (i.e., "clay" soils) do not identify their tendency to disperse in the presence of relatively pure water (Sherard and Decker 1976).

92. Experiences of Sherard and Decker (1976) suggest that dispersive clay materials are generally present in floodplain deposits, slope wash, lake bed deposits, and weathered loessial deposits. In contrast, all nondispersive clay materials have been derived from the in situ weathering of igneous and metamorphic rocks, and from limestones. In other parts of the world, dispersive clay materials reportedly occur in parts of Australia, Israel, Ghana, Venezuela, Mexico, Brazil, Trinidad, South Africa, Thailand, and Vietnam.

93. In the United States, the most severe problems with dispersive clay materials have been reported in Kansas, Nebraska, Oklahoma, Tennessee, Mississippi, northeastern Arkansas, and in southern Texas (the Beaumont Formation) in conjunction with badly eroded SCS dam and channel sites (Sherard and Decker 1976). In the Western United States, the high-sodium soils are predisposed to dispersion (Decker and Dunnigan 1976). The nonsaline-alkali soils in arid and semiarid parts of several Western states also exhibit a marked predisposition to deflocculate or disperse in water. The full extent and natural occurrence of dispersive clay materials have not been documented; this is an area which

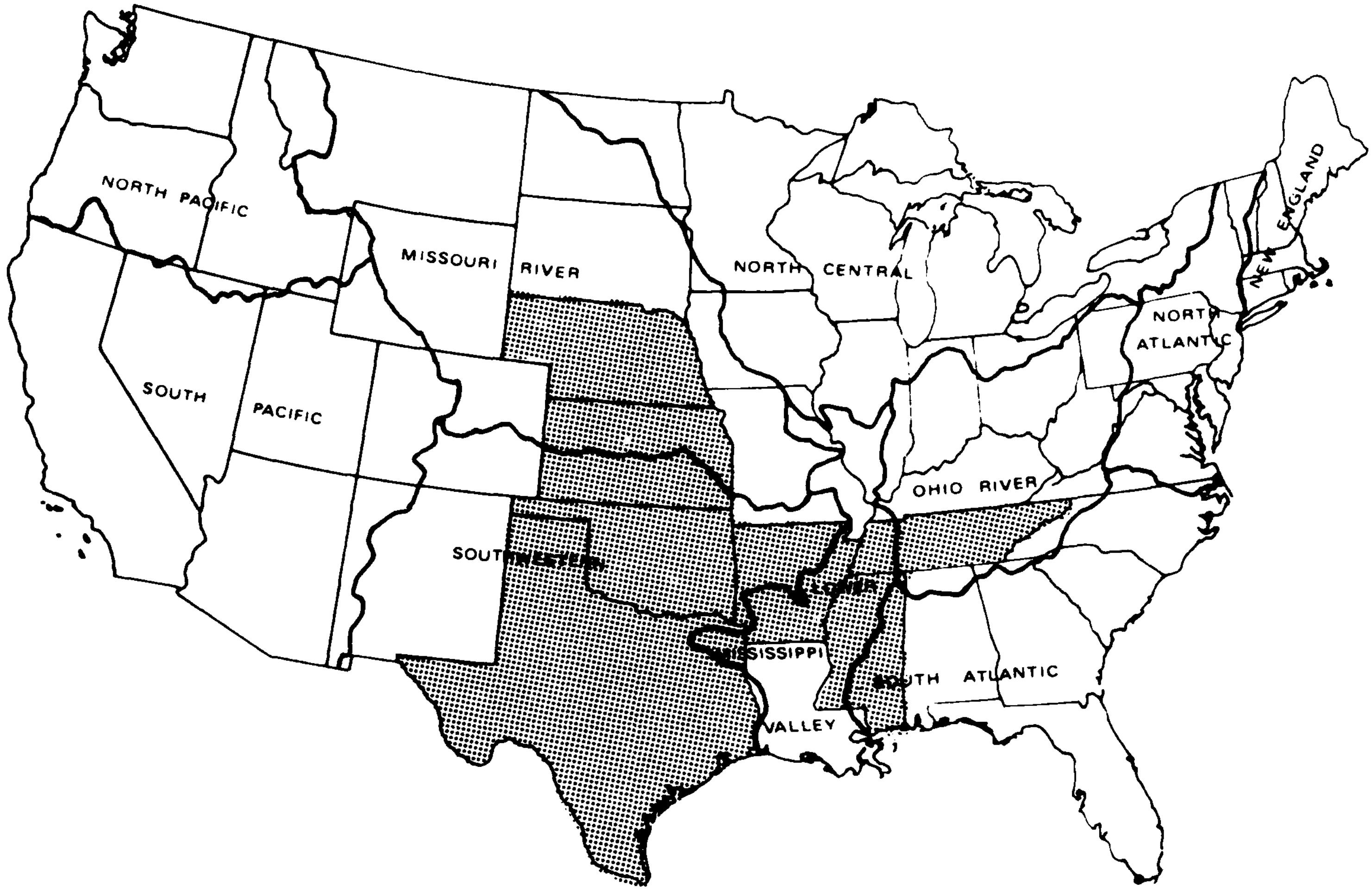


Figure II-15. Potential occurrence of dispersive clay materials

clearly requires more study. Figure II-15 also incorporates any reports of the occurrence of dispersive clay material following land disturbances at specific locations.

Wind erodible soil materials

94. Definitions and limitations. Finely divided soil particles that become airborne when exposed to the wind are defined as wind erodible. Conditions conducive to wind erosion are a wind velocity of 12 to 15 mph at 1 ft above the land surface. Wind erosion can occur on bare, smooth, and dry soil surfaces consisting of lightweight soil particles such as very fine sand, loamy fine sand, sapric, and humic organic soil materials (Woodruff et al. 1972). Wind erosion can be a problem on bare soils in seasons of low rainfall, high surface temperatures, rapid evaporation, and high windspeeds. Exposed and nonvegetated soil surfaces dominated by fine silt particles (as in loess), very fine sands, and lightweight muck and peat soils are the first to become airborne. Coarse sand particles, on the other hand, do not readily become airborne because of their heavier weight. When dried sufficiently, however, they are easily moved by saltation or surface creep. Table II-3 shows the relation between soil particle size and its transportation. Wind erodibility for different soil textures is shown in Table II-4. Wind erosion and dust generation decrease as soil moisture increases.

95. The following factors influence the degree of susceptibility of problem soils to wind erodibility (South Dakota State Conservation Commission, no date):

- Soil type.
- Type, kind, and amount of vegetative cover.
- Strip width and direction relative to prevailing winds.
- Wind barriers.
- Topographic conditions and surface roughness.

Tables and formulas that incorporate all of the above factors are widely available to determine soil loss due to wind (Craig and Turelle 1976).

96. Dust and soil particles generated under a wide variety of conditions can adversely affect the safety of personnel and damage housing areas and facilities and engines (US Department of Defense, no date). These airborne soil particles also can seriously damage plant materials.

Table II-3

Types of Soil Particle Transporation and Diameter Size*

Types of Particle Transporation	Diameter of Particle
Atmospheric suspension	Smaller than 0.1 mm in diameter
Saltation	0.1 mm to 0.5 mm
Surface creep	0.5 mm to 3 mm

* Sultan and Fleming (1974).

Table II-4

Wind Erodibility Groups (WEG) and Soil Erodibility Index*

WEG	Soil Texture Classes	Wind Erodibility Index (I) tons/acre/year
1	Very fine, fine, medium, and coarse sand**	310
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric organic** soil materials	134
3	Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam	86
4	Clay, silty clay, noncalcareous clay loam, or silty clay loam with more than 35 percent clay	86
5	Noncalcareous loam and noncalcareous silt loam with less than 20 percent clay, sandy clay loam, sandy clay, or humic organic soil materials	56
6	Noncalcareous loam and noncalcareous silt loam with more than 20 percent clay, or noncalcareous clay loam with less than 35 percent clay	48
7	Silts or noncalcareous silty clay loam, with less than 35 percent clay	38
8	Very wet or stony soils usually not subject to wind erosion	--

* USDA, SCS (1980).
** Always use unridged condition due to instability.

97. Special limitations arise with reference to excavation and related disturbances of loess soil materials. The sloughing of slope faces has challenged engineers confronted with excavation in loess soils for many years. In addition, cut slopes in loess are easily rutted, gullied, and tunneled. The disposal of excavated loess can present problems of instability and susceptibility to wind erosion unless steps are taken to provide an early cover of vegetation or mulch materials (Turnbull 1968).

98. Occurrence. Exposed surface soil materials that are known to be prone to wind erosion reportedly occupy approximately 3 percent of the contiguous United States (USEPA 1973b). Soil losses by wind erosion are considered a minor source of water pollution compared to that by water erosion. But in localized geographic areas, wind erosion can be a significant nonpoint source of contaminants in the air, water, and on land (US Department of Defense, no date).

99. The general distribution of upland surficial soil materials that are prone to severe wind erosion is shown in Figure II-16. The largest potential hazard areas of wind erodible soils occur in the northern, central, and southern Great Plains states of North and South Dakota, Nebraska, eastern Colorado, southwestern Kansas, northwestern Oklahoma, and western Texas. Other Western areas prone to severe wind erosion are northern Montana, southeastern Wyoming, southern Colorado, New Mexico, Arizona, western Utah, northwestern Nevada, and eastern Washington (Utz et al. 1938). In the Central United States, wind erosion of exposed soil materials can be a problem in Minnesota, Wisconsin, southern Michigan, and northwestern Indiana (Utz et al. 1938). In the Northeastern United States, seasonal wind erosion can be serious locally on upland areas in southern New Jersey, southern Delaware, and the eastern shore of Maryland and Virginia (USDA, SCS 1980).

100. Excavated loess, when dumped indiscriminately as fill, can present serious wind erosion problems in certain areas, as shown in Figure II-17. The major deposits of loess occur along the eastern side of the lower and central Mississippi Valley, Iowa, Nebraska, and western Kansas. Further to the West, important loess areas occur in central and southeastern Washington, and in southeastern Idaho (Turnbull 1968).

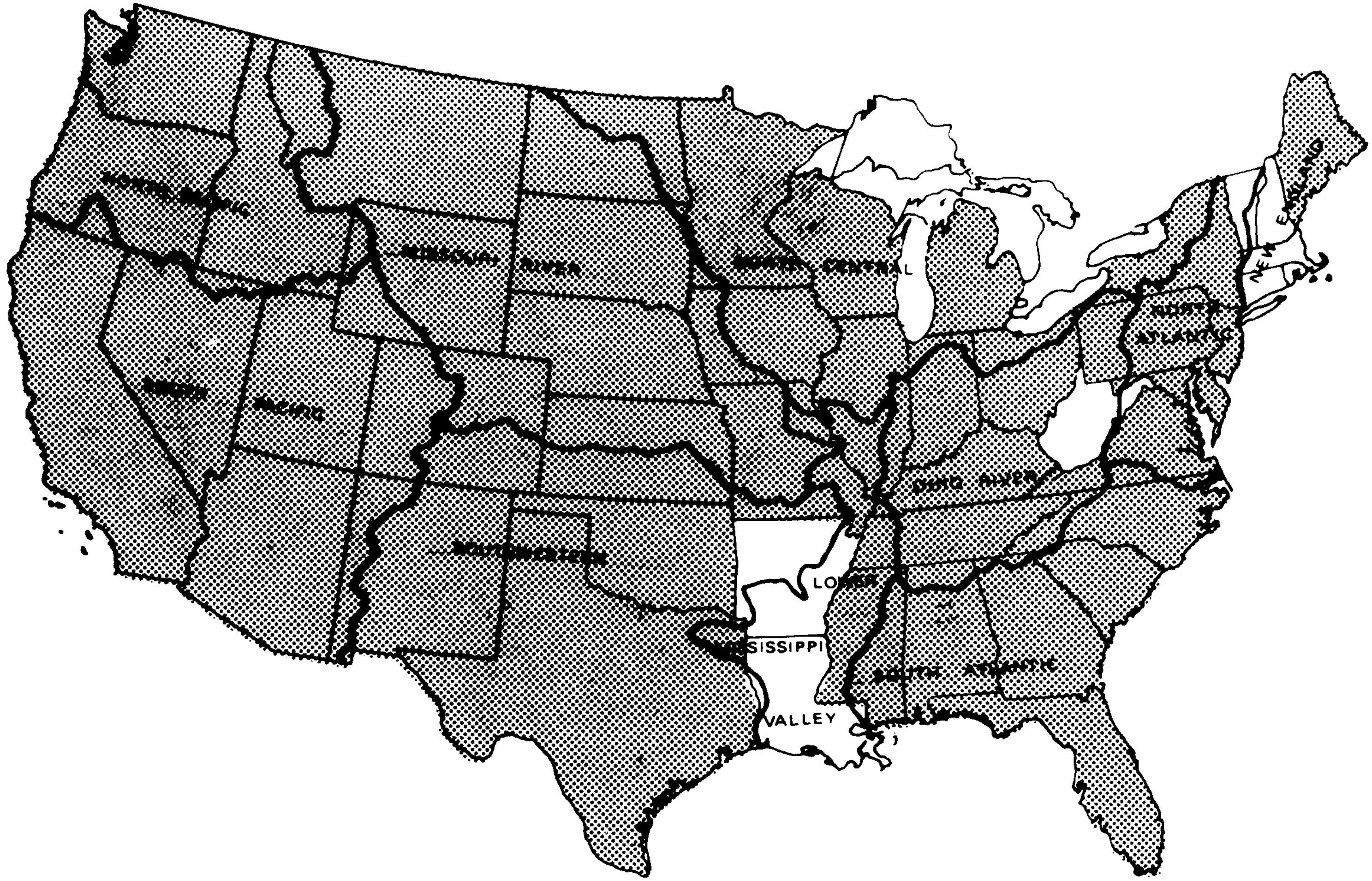


Figure II-16. Potential occurrence of wind erodible soils (No data were found on wind erodible soils in West Virginia, Arkansas, and parts of Louisiana)

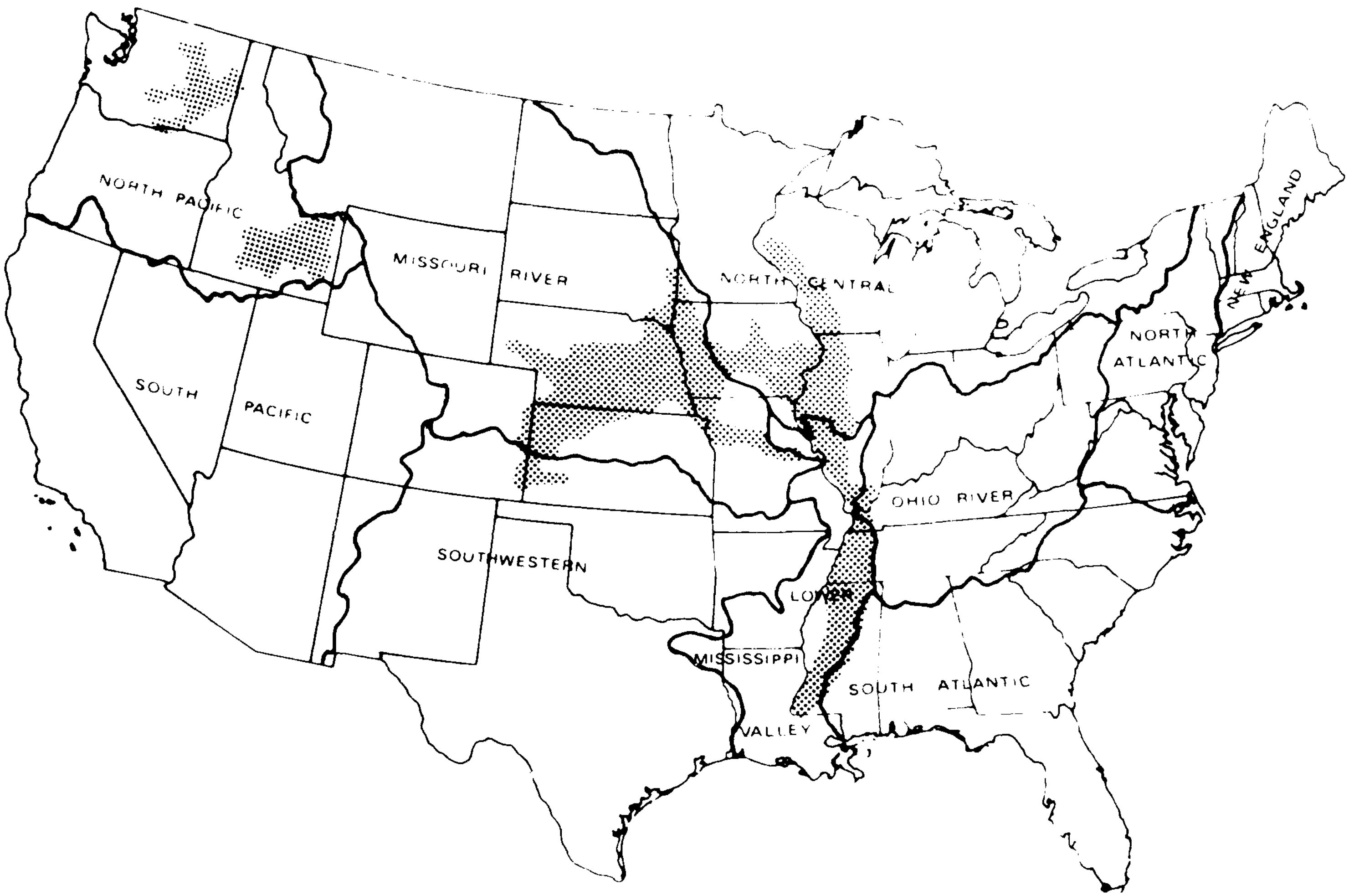


Figure II-17. Dispersion of loess

Table III-2 (Continued)

Soil materials (Continued)
• Depth over bedrock
• Presence of highly erodible soils
• Identification of suitable topsoiling material
• Substrata characteristics/pyritic materials
Vegetation
Indicator plants (offsite)
• Plant succession (identification of suitable native species)
• SCS - Land Resource Area (for plant material recommendations)
• Ecosystem/ecoregion
• Habitat suitability for wildlife
• Endangered plant species
Climate
• Average seasonal precipitation
- Snow
- Rain
• Average direction and velocity of prevailing winds
• Seasonal temperature ranges and growing seasons
• Evaporation rates
Land management alternative/options
• Endangered species and/or critical habitat
• Fish and wildlife uses
• Forestry uses
• Recreation uses
• Agriculture uses
Visual resources
• Appearance (character type and variety class)
• Uniqueness or desirability
• Sensitivity level (visibility)

(Continued)

(Sheet 2 of 3)

Table III-2

On-the-Ground Checklist for Field and Laboratory Surveys

Topography

- Elevation
- Major slope gradients and lengths
- Major slope aspect/direction
- Land instability problems
  - Land subsidence
  - Slide hazard
  - Other
- Microrelief

Hydrology

- Location of all surface water bodies
- Surface drainageways
- Water quality
  - Sediment/visual muddy water
  - Acidity/pH
  - Trace elements
- Ground water flows
  - Perched water table
  - Hardpans
  - Clay lenses
  - Depth of water table (including seasonal variations)
- Seepage areas
- Erosion hazard and potential soil loss
  - Gullies
  - Sheet erosion
  - Rill erosion
  - Wind erosion

Soil materials

- Soil/core sampling plan
  - Bulk density/compaction
  - Color, texture, and pH
  - Fertility
  - Potential toxicity of trace elements/heavy metals
  - Permeability
- Regolith classification
- Profile characteristics

(Continued)

(Sheet 1 of 3)

121. Input from support staff (e.g., contract administrator, specifications writer, and other support staff such as photointerpreters) should be integrated with that of the survey team as the survey progresses. This is necessary in order to expedite the preparation, selection, and contracting of the most effective site restoration plan based on assigned restoration priority ratings. The potential scope of on-the-ground surveys is illustrated by the checklist in Table III-2. In practice, only a few of these items would be examined on any given site.

122. Problem identification. Basic to problem identification is the identification of resource management problems and public perceptions, the analysis of these problems, the assignment of restoration priority ratings to project sites, and the synthesis of all essential information into site-specific planning objectives. The major objectives of problem identification include, as a minimum:

- Laboratory tests to determine physical and chemical characteristics of soil materials.
- Selection of measures required to stabilize and revegetate the site(s) directed toward the control of soil erosion and the protection of water quality.
- Assignment of restoration priority ratings to project sites.
- Application and maintenance of land management plans that will upgrade and enhance the biological productivity of the site(s) with reference to wildlife, recreation, and other land uses.
- Determination of the need to conduct greenhouse and field research on selected remedial treatments.

Information sources which can supply information pertinent to landscape management, land uses, wildlife values, recreation, aesthetics, and the upgrading of biological potential are given in Appendix G.

Stage three - develop restoration plans

123. Upon completion of stages one and two, a report should be prepared that includes, but is not limited to, the following items:

- The location, scope, and description of the critical problem areas.
- The structures (temporary and permanent) that must be put into place either at upstream locations or on the project site itself for the control of sheet flow/concentrated flow of water or otherwise provide protection sufficient to accomplish the satisfactory stabilization of the site.

- The hydrologic character of land areas located above and downstream of the project site.
- Site areas that are devoid of living vegetation.
- Site areas of apparent uniformity of rock types and exposure at the soil surface not previously documented.
- High density drainage areas on the site which indicate active erosion and a relatively high amount of surface runoff not previously documented.
- Major vegetation types not previously documented.
- Areas of unique or sensitive visual resources.

118. During stage one the special problem areas should be flagged. These areas might include:

- Potential relocation of access roads.
- Potential routes for new access roads.
- Potential requirements for maintenance of roads and trails.

Stage two - on-the-ground reconnaissance and problem identification

119. On-the-ground reconnaissance. Before the interdisciplinary team commences the stage two reconnaissance survey, the following items should be obtained:

- Resource and/or land management goals, needs, and constraints specific to a project site, as these factors relate to the watershed as a whole.
- The best available maps and copies of all relevant documents depicting project boundaries, offsite conditions, and the location and extent of critical areas at a project site.
- All site-specific information relating to soils, climate, hydrology, core sampling, and other useful data.
- The deadline for completion of the survey and the date required for delivery of the most cost-effective site restoration plan.
- Selection of members of planning team from appropriate disciplines based on site-specific goals.

120. An onsite survey might include the following items of interest:

- Determination of soil properties on critical areas.
- Vegetation survey.
- Topography.
- Climate.
- Hydrology.
- Visual resources.

Methodology for these surveys are discussed in Appendix C.

116. Aerial photographs, US Geological Survey base maps, and related tools are most useful in stage one. For example, items within the survey area that can be located on aerial photographs include: (a) land areas subject to hazards from soil erosion and sediment, (b) watershed conditions that threaten to increase sediment and overland flows, and (c) sensitive ecosystems and other areas of critical environmental concern. Items of interest under each of these categories include, but are not limited to, the following:

- Land areas subject to hazards from soil erosion and sediment:
  - Recreation development.
  - Fish and wildlife habitat.
  - Community and urban development.
  - Municipal and domestic water supply.
  - Transportation systems.
  - Water distribution systems (irrigation).
  - Agricultural development (crops, facilities).
  - Industrial development (dams, power, manufacturing).
  - Power and communication lines.
- Watershed conditions that threaten to increase sediment and overland flows:
  - Water-repellent and impermeable soils.
  - Areas of mass instability subject to slides, slumps, slips, and mudflows.
  - Existing or potential water pollution problems.
  - Improperly placed access roads.
  - Poor agriculture and/or silviculture practices.
- Sensitive ecosystems and other areas of critical environmental concern:
  - Floodplains.
  - Off-road vehicle trails on public lands.
  - Wetlands.
  - Wilderness areas.
  - Endangered species and their critical habitat.

117. The primary purpose of these initial observations is to observe site indicators considered useful for mapping homogeneous units within which certain hydrologic conditions will be determined. Site indicators of interest include, but are not limited to, the following:

114. The initial objectives of the project site evaluation are identical to those stated earlier. Other objectives, discussed later in this section, include the long-term enrichment of site productivity for wildlife, recreation, and other acceptable land uses identified through public participation and other activities.

Stage one - general site description

115. The primary goal of the generalized survey (i.e., stage one) is to describe existing site conditions and verify the actual location, nature, and extent of significant problem soils that must be restored at designated project sites. As a general rule, the stage one survey should be completed before commencing the more detailed stage two survey. This process is advisable because it is essential to provide the stage two survey team (whose structure may be entirely different from that of the stage one team) with the necessary background information on each project site. The general site description checklist shown in Table III-1 illustrates the type and scope of information that is usually needed.

Table III-1

General Description Checklist

- Project boundary/watershed boundary
- Aerial photographs
- Individual potential problem area(s) location/size
  - Borrow areas
  - Cut slopes
  - Disposal sites
  - Fill slopes
  - Barren natural areas
  - Semi-improved areas
  - Unimproved areas
- Access roads
- Existing structures/fences
- Existing land uses (offsite and onsite)
- Existing water uses (offsite and onsite)

- Soil Conservation Service (technical services centers, plant materials).
- District foresters and district soil conservationists.
- Science and education administration.

- State agricultural experiment stations.
- US Department of the Interior
  - US Fish and Wildlife Service.
  - Bureau of Land Management.
  - Bureau of Reclamation.
  - US Geological Survey.
- Tennessee Valley Authority.
- River Basin Commissions.
- Public Interest and Conservation Groups.
- US Department of Commerce.
  - National Marine Fishery Service.

Site Survey and Evaluation

112. The interdisciplinary team approach should be used to: survey all critical areas on project sites; determine site-specific restoration needs; and develop site restoration plans based on assigned restoration priority ratings.

113. A three-stage survey (Riggins et al. 1975) is recommended for designated project sites as follows:

Stage one - A broad, generalized site investigation should be conducted at the project site(s) relating to the subwatershed(s)/watersheds as a whole. These surveys are to be completed before stage two commences since they will provide the background information to focus upon "significant" resources to be examined in further detail in subsequent stages.

Stage two - Somewhat detailed on-the-ground reconnaissance surveys should be conducted to identify and assess the nature and extent of all significant problem soils prior to the development of site restoration plans.

Stage three - Based on the information obtained in stages one and two, the most effective site restoration plan should be developed and selected. The most cost-effective plan will be integrated into the detailed environmental provisions (DEP) of the site restoration contract.

- Soil Scientist/Agronomist.
- Plant Materials Specialist/Landscape Architect.
- Hydrologist or Geohydrologist.
- Design Engineer.
- Terrestrial Ecologist.
- Recreation Specialist.
- Contract Specification Writer.
- Wildlife Management Specialist.
- Support Services (draftsman, typist, photointerpreters, as needed).

It is unlikely that all of these skills would be needed for the general survey except on the most complex sites. As site-specific alternatives are developed it may be appropriate to solicit the opinions of other experts as the occasion and resource categories warrant.

Coordination within
the Corps of Engineers

110. An appropriate liaison should exist within the Corps unit responsible for organizing the project site and surveying team for organizing and implementing an effective communications and information exchange network for all stages of work to be performed at specific project sites. Those persons who are involved with Corps operations, at both the technical and administrative levels, should be updated and briefed at all times during the processes of planning, advance engineering and design, construction, and operation and maintenance relative to the specific project sites. Coordination between planning, construction, operation, and maintenance units is desirable for the restoration of a project site as it draws upon the collective expertise of the District rather than a single organizational element.

Coordination between other agencies

111. Appropriate liaison should occur between all non-Corps land and water resource development agencies and programs. These include the following government and government-related groups:

- State and local natural resource departments.
- Colleges of agriculture, state land grant universities.
- US Department of Agriculture.
  - Forest Service (state/private forestry and national forestry).

and threatened species (both state and Federal listings), critical habitat (designated by USFWS), aesthetic values, and cultural resources such as archeological sites, historic places, and resource remnants with scientific and educational uses.

107. In meeting the essential elements of a sound iterative planning process, planners should:

- Plan with an interdisciplinary team composed of individuals who represent a broad scope of expertise.
- Identify site problems and needs through public participation.
- Identify and list site features or conditions which could be enhanced, protected, preserved, restored, or developed.
- Formulate a wide range of alternatives to achieve the objectives of economic development and environmental quality based on established restoration priority ratings for the project sites.
- Present feasible alternative proposals based on established priority ratings as to highly critical and/or sensitive areas.
- Seek to reduce or eliminate significant adverse effects on the environment by modifying the alternatives considered for implementation to the fullest extent feasible, in order to provide partial or full solutions to identified problems and needs.
- Select, for implementation, the land restoration plan that best represents the assigned restoration priority ratings and the public interest as a result of evaluating all pertinent site factors.

Interdisciplinary team

108. Essential considerations requisite to the site planning process include: the interdisciplinary character of the planning team; flexibility in each stage of the planning process; implementability of the detailed plans; and institutional analysis. Only the first of these considerations is discussed here. An interdisciplinary planning approach is required in order to identify and define planning objectives; assign restoration priority ratings for the project sites; develop valid alternative remedial plans; and analyze the consequences of implementing each alternative.

109. The makeup of an interdisciplinary project site survey team will vary according to the size, complexity of the site, and types of unique resources. The disciplines appropriate for the conduct of a general survey to assess the restoration requirements on specific project sites are suggested to be drawn from the following:

- Description of the amount of annual precipitation, length of growing season, seasonal distribution of rainfall, elevation, macrorelief and microrelief at the site, and land uses adjacent to the project site(s).
- Assignment of restoration priority ratings to the problem soils.

Other aspects of project site descriptions are discussed later in this part, with particular emphasis on the preparation and evaluation of after-the-fact, site-specific restoration plans. As pointed out in Section I, the information presented herein is generally applicable to new projects.

Planning Objectives

105. The major objectives of planning the after-the-fact improvement of problem soil areas on project sites are to:

- Identify and evaluate the most critical and/or sensitive areas on a watershed basis and plan the appropriate corrective actions to stabilize and revegetate these areas (i.e., as an absolute minimum, implement only the needed erosion and sediment control measures on a portion of the entire watershed).
- Ensure appropriate liaison within the Corps, and between all non-Corps land and water resource development agencies and programs.
- Identify and evaluate the potential land use and habitat enhancement opportunities on project sites with emphasis on fish and wildlife, recreation, and forestry land uses at nonreservoir and reservoir sites to:
  - Ensure the timely availability of any land and water resource information needed to make effective choices regarding land management under existing and projected conditions at specific project sites.
  - Develop and fully integrate appropriate watershed management goals and objectives into land and resource management planning for specific project sites.
- Assign restoration priority ratings and formulate alternative plans (including no action) for project sites without bias as to the use of structural or nonstructural remedial measures for reservoir and nonreservoir sites.

The multiobjective planning process

106. During all phases of the site planning process, careful consideration should be given to recognized authorities, responsible professional judgments, and other public expressions on environmental aspects, including, but not limited to, water and air quality, fish and wildlife resources, endangered

SECTION III: PLANNING THE RESTORATION OF PROBLEM SOIL MATERIAL SITES

102. The planning process is basic to the identification and resolution of problem soil areas encountered at project sites. The approach to planning site restoration of these areas will be discussed on a sound technical basis that can be incorporated into the institutional requirements already established by the Corps of Engineers. Discussion of these institutional requirements is beyond the scope of this report, but it is emphasized that restoration plans must satisfy these institutional requirements.

103. The problem soil areas known to exist on various project sites and facilities occur as a result of a wide range of land disturbing activities. Types of construction site activities have been identified, as follows:

- Excavated material disposal sites.
- Cut slopes.
- Fill slopes.
- Borrow areas.
- Semi-improved grounds.
- Unimproved grounds.
- Embankments, levees, and dikes.

104. The extent and magnitude of these problem soil areas are presently unquantified on project sites, but their occurrence is reported throughout the United States. Descriptions of these areas should be given, as a minimum, in the following terms:

- Delineation of all problem soil areas on a watershed (base) map, according to problem soil class or classes for selected project sites.
- Quantification of the acreage and total number of the problem soil areas (according to problem soils and site conditions) relative to the project site as a whole.
- Description of the watershed as a whole and the orientation of the project site(s) within the watershed(s) in relation to adjacent private lands, downstream areas, scenic rivers, cultural resources, natural areas, national forests, state forests, prime farmlands, national landmarks, and other significant land features.

SECTION III: PLANNING

SECTION III: PLANNING THE RESTORATION OF PROBLEM SOIL MATERIAL SITES

101. Organic soils in Northern areas occur largely in the Great Lake states, northwestern New Jersey to Minnesota and Illinois, northeastern Maine, northern Idaho, and northern and western Washington (USDA Soil Survey Division 1938). In the Southeastern United States, extensive areas of muck soils occur in the level, upland Pamlico terrace along the Southeastern Atlantic Coastal Plain. Muck and peat soils in the Gulf Coastal Plain occur typically in the Everglades of Florida (the Okeechobee muck). In California's Sacramento-San Joaquin delta area, various peat soils have accumulated on flat terrain (USDA Soil Survey Division 1938).

Table III-2 (Concluded)

Factors to be considered in assigning restoration priority rankings to project sites

- Proximity of the sites to:
  - Sensitive ecosystems
  - Endangered species of plants and animals and designated critical habitat of significant wildlife resources
  - Prime farmland
  - Prime water supplies (surface and aquifer sources) and other established and/or sensitive land and water resources
- Onsite occurrence of highly critical problem soils that include, but are not limited to:
  - Strongly acid soils
  - Acid drainage areas/disposal sites
  - Soils with excessive internal drainage
  - Dispersive clays exposed by construction
  - Highly wind erodible soils exposed by construction
  - Highly saline-sodic soil materials exposed by grading, borrowing, etc.
- Unusual hydrologic characteristics of land areas located above and downstream from the project sites
- Areas of unique or sensitive visual resources
- Watershed conditions as a whole that threaten to increase overland flow of water and sediment, thereby threatening to destabilize the project site(s), either during or following selected land restoration measures.

(Sheet 3 of 3)

- The delineation of unstable areas; areas to be irrigated, leached, or drained; areas to receive extensive soil conditioning; areas to be treated with lime and fertilizers; and areas to receive soil plating treatments.
- Measures necessary to modify, as necessary, all unduly long and steep slopes, and to relocate access roads, haul roads, ditches, basins, and drainageways.
- The identification and evaluation of the most cost-effective land treatment alternatives and options for management, maintenance, overall environmental protection measures, and wildlife, recreation, and other land uses appropriate to the project site(s).

124. Alternative plans are developed and modified via an iterative process until a plan is selected that is most likely to preserve, maintain, restore, or enhance the natural and cultural resources and ecosystems associated with specific project sites in the most cost-effective manner. The level of restoration effort will be reflected in the assigned restoration priority rating for the area. Wherever acceptable, the "no action" alternative shall be formulated.

125. The development of alternative plans will involve:

- Setting forth a broad range of technical and institutional measures (structural and nonstructural) that will satisfy the different interest groups and be acceptable to Corps goals.
- Identifying plans proposed by other governmental or nongovernmental interests.
- Establishing a basis for effective choice among plans.

126. The formulation of alternatives must be solidly based on site-specific soil, hydrologic, topographic, climatic, and other significant characteristics reported for the different problem soil areas, with reference to the watershed/subwatershed as a whole. Soil losses by sheet, wind, and rill erosion and mass wasting processes must be predicted. Analyses should be made of the resulting impacts of contaminant runoff on water quality, site productivity (both onsite and offsite), fish and wildlife habitat, endangered species, and wilderness characteristics. Consideration must also be given to the potential cost-effectiveness of various land treatment measures, including soil conditioning, seeding, planting, fertilizing, and liming (USDA, Forest Service 1980a). Finally, the alternatives must be compatible with the long-term land management goals and established policies for Corps projects.

127. The interdisciplinary team will formulate a reasonable range of alternatives to provide different ways to address and respond to resource

opportunities, major public concerns, and management concerns identified by the interdisciplinary team (USDA, Forest Service 1980c).

128. The interdisciplinary team should develop criteria for the evaluation of alternatives. These criteria should be based on the following suggested considerations:

- The alternative must meet the first land treatment objective for the control of overland flows of water and sediment deposition.
- The prescribed structural and other remedial measures must be feasible to install and be effective with reference to each of the problem soil areas.
- The prescribed measures must be environmentally and socially compatible with long-term land management goals and land-use objectives.
- The alternative must provide the most cost-effective treatment(s) with reference to each of the problem soil areas and the relative importance of the site.

129. For example, Table III-3 presents a matrix that was used by the Forest Service for the evaluation of alternatives for the rehabilitation of burned areas in the White River National Forest of Colorado (USDA, Forest Service 1980b). Alternatives were evaluated using criteria similar to those cited in the previous paragraph. Each of the five alternatives was then ranked in accordance with evaluation criteria. Alternatives (2) and (3) met or partially met all the established criteria. The cost-effectiveness ratios of these two alternatives were 2.42 and 4.56, respectively, as shown in Table III-4. Alternative (3) was selected because of its greater cost-effectiveness.

Land-Use Planning

130. Enhancement of problem soil areas through the incorporation of land uses appropriate to the particular site is an integral part of the site restoration/improvement plan. Recommendations for long-term land management goals are made by the interdisciplinary team as part of the site evaluation process. The fact that errors in the use of land and its natural resources may take years to correct makes it important that this be a well-thought-out and planned process.

Table III-3

Evaluation of Alternatives for Rehabilitating a Burned Area in White River National Forest*

	Alternatives				
Evaluation Criteria	(1) No Action	(2) Seed High and Mod. Burn Areas + Remove Debris	(3) Seed High Burn Areas + Remove Debris	(4) Seed High and Mod. Burn Areas	(5) Seed High Burn Areas
Meets rehabilitation objectives by mitigating potential damage to:					
Onsite productivity	3	1	2	1	2
Stream channel equilibrium	3	2	2	2	2
Fisheries	3	1	1	2	2
Onsite downstream property from effects of floods	3	1	1	3	3
Alternatives are feasible	N/A	1	1	1	1
Alternatives are environmentally and socially acceptable	3	1	1	2	2

Key: 1 = Meets evaluation criteria; 2 = Partially meets evaluation criteria; 3 = Does not meet evaluation criteria.

* USDA, Forest Service (1980b).

Table III-4

Cost-Effectiveness for the Rehabilitation of a Burned Area in the White River National Forest*

Alternative	Treatment Area, acres	Cost	Cost-Effectiveness Ratio
(1) No action	--	--	--
(2) Seed high- and moderate-intensity burn areas and remove debris	6300	$225,750	2.42
(3) Seed high-intensity burn areas and remove debris	2500	$ 95,850	4.56
(4) Seed high- and moderate-intensity burn areas	6300	$218,750	1.72
(5) Seed high-intensity burn areas	2500	$ 93,850	3.17

* USDA, Forest Service (1980b).

131. Suitability of a project site to a particular land use is determined by the natural and to a lesser extent the geographic factors of the area. Geographic factors are defined here as an embodiment of spatial, economic, and market considerations. Together these factors will, to a large extent, determine the demand and thus the value of the site for various land-use types. Natural factors are organized under three broad headings: geomorphic factors, soil factors, and climatic factors. These natural factors encompass the active forces, which include all the climatic factors that are fixed by geographic location and are generally beyond control, and the passive forces which include all the soil factors plus the geomorphic elements of topography, slope, and drainage, which are elements that can be affected and modified by the restoration process (Clar 1978).

132. An evaluation of these factors as part of the general site description and the on-the-ground survey provides inputs to the contract provisions of the site restoration/improvement plan. Table III-5 contains information on factors that determine the land-use suitability of a site.

Wildlife land uses

133. Restored project sites are often well suited for wildlife development. With land for wildlife uses shrinking at an alarming rate, the use of restored lands as habitats for wildlife should be considered. These sites can be used for wildlife alone or integrated with other types of planting for multiple-purpose use. Corps policy requires that wildlife land-use programs be closely coordinated with Federal, state, and local wildlife groups.

134. A number of factors must be considered for proper development of project lands into wildlife uses. The factors which determine wildlife habitat suitability are outlined in Table III-6. The interdisciplinary survey team should evaluate these factors in relation to specific sites and their soil conditions.

135. Further up-to-date information on evaluation of wildlife land-use and habitat evaluation procedures can be obtained from Mr. C. A. Martin or Ms. J. H. O'Neil, Environmental Laboratory, Environmental Resources Division, WES, telephone (601) 634-3111.

Recreational land uses

136. Corps projects are sometimes suited to various recreational activities as a final land use. This is true for both reservoir and nonreservoir sites alike, although reservoir sites are often the most suitable. Although

Table III-5

Factors that Influence the Land-Use Suitability of a CWP Site

Factor	Descriptor	Remarks
Geographic	Location	Fixed variable
	Accessibility	Determined by travel distance and time
	Size and shape	Changed only by subdivision of project site
	Surrounding land uses	Present use and trends
	Intensity of use	
Climatic	Temperature	Major climatic factors are fixed
	Humidity	
	Precipitation	
	Solar radiation	
	Wind	
Geomorphic	Topography	
	Slope	Degree of slope limits the intensity of development
	Drainage	Projects often substantially change drainage patterns
	Altitude	
	Exposure	
Soils		
Agricultural properties	Soil profile	Characteristics of surface soil layers in a natural state or after treatment
	Texture	
	Structure	
	Organic matter	
	Moisture content	
	Permeability	
	pH	
	Depth to bedrock	
	Color	
Engineering properties	Shrink-swell potential	Characteristics of the largely inorganic subsoil and substratum soil layers. Primarily determines their ability to support loads.
	Wetness	
	Erodibility	
	Flood hazard	
	Slope	
	Bearing capacity	
	Corrosion potential	
	Ease of excavation	

Table III-6

Factors that Determine Wildlife Habitat Suitability*

Factor	Remarks
Water	Requirements vary widely with species
	Mobility and migratory habits must be considered
Food	Wide variation of requirements among species
	Successional stage of vegetation greatly influences feed availability
	Seasonal fluctuations need to be considered
Cover	Requirements vary widely among species
	Provides nest sites and resting and bedding grounds
Edge effect	Defined as the linear measure of the borderline between two distinct vegetation types
	Very attractive to wildlife
	Particularly important for species with limited range and mobility
	Interest and importance to a particular species varies with type of edge
Damages	Defined as destruction of forage, herbage, seeds, planted seedlings, and cultivated crops by wildlife
	Protection from wildlife is sometimes required to protect vegetation
	See Section V "Vegetative Stabilization of Problem Soils"

* Clar (1978).

recreation can imply the construction of facilities such as golf courses, arenas, and swimming pools, these uses are not ideally suitable for most project sites. These activities are more suited to improved and semi-improved ground areas at certain project sites and installations operated by the Department of the Army.

137. There are three basic types of recreation areas: (a) resource-oriented areas which possess scenic, scientific, or historic significance; (b) user-oriented sites that provide activities for a large number of people; and (c) intermediate sites which are a combination of resource- and user-oriented areas and are exemplified by Corps reservoir projects. A number of the geographic and natural factors previously mentioned determine the suitability of a particular site for recreational activities. Table III-7 lists the most important of these considerations. The interdisciplinary survey team should evaluate these factors in relation to the conditions at a particular site.

138. There are two main considerations when choosing vegetation for recreational land-use areas (Countryside Commission 1980). The first is the height of the required vegetation, which will be determined largely by the planned use. For example, picnic sites will consist usually of a short turf, whereas medium to long grass might be more appropriate for areas of visual importance. The second consideration is the necessary wear-tolerance. Grass species vary considerably in their tolerance to wear and in their ability to recover from wear. For example, perennial ryegrass is the most hard-wearing species and forms a very wear-tolerant sward when used in combination with other grasses such as timothy and smooth meadow grass. On the contrary, creeping red fescue and common bent are relatively intolerant of heavy wear and also show poor recovery from wear (Countryside Commission 1980). The following recreational areas will be considered in the listing of appropriate vegetation in Appendix E:

- General informal recreation areas.
- Areas of visual importance.
- Grassed parking areas.
- Campsite.
- Picnic areas.
- Areas under trees.

Table III-7

Influence of Geographic and Natural Factors on Recreational Land Use*

Factor	Remarks
Location and access	All recreation activities are distance related
	Adequate access routes are essential
Size and configuration	Size requirements vary with the type of recreational activities
Surrounding land uses	May limit the suitability of a site for recreation
Climate	Both contribute to and limit recreational activities
	Climate should be appraised as a relative matter for many situations
Geomorphology	Topography and slope have a direct effect upon the suitability of a recreational activity
	Aesthetic qualities should be considered
	Drainage and water features are very important in recreational areas
Soils	Each soil type has a degree of limitation which determines its suitability to support a recreational activity
	A knowledge of soil conditions is essential
	Soil conditions can vary widely over a site

* Clar (1978).

- Sand dunes.
- Damaged footpaths.

Although aftercare and maintenance must be kept to a minimum for economic reasons, they should be tailored toward the desired end product. Addition of fertilizers is almost always necessary during early vegetative establishment, but is all too frequently forgotten. Where the vegetative cover includes legumes, the need for additional nitrogen fertilizer will be minimized; it may only be necessary to add phosphorus fertilizer and perhaps lime. However, a solely grass vegetative cover will require repeated applications of nitrogenous fertilizers if the vegetative cover is not to degenerate and become susceptible to wear (Countryside Commission 1980).

139. Further up-to-date information can be obtained from Dr. A. J. Anderson, Natural Resources Research Program Manager, Environmental Laboratory, WES, telephone (601) 634-3111.

Other land uses

140. Other possible land uses at restored/improved project areas include agriculture and forestry. Residential, commercial, institutional, and industrial land uses that are sometimes considered as land management goals do not follow the policies, objectives, guidelines, and regulations pertaining to the US Army Corps of Engineers Civil Works projects. In most instances, the Corps is interested in short-term land uses for areas that will be turned over to another jurisdiction or government agency after the construction and site restoration have been completed.

141. The amount and type of land required for agricultural land use place tight restrictions on the suitability of a site. Large areas that are level or gently sloping are generally necessary. By their nature, project sites generally do not provide areas that would allow for agricultural land uses.

142. With reference to forestry land uses, project sites generally do not lend themselves to a monoculture system for timber or biomass production. Should conditions be such that timber or biomass production was found preferable to other land uses such as recreation, wildlife, and water resources, the Corps should coordinate its planning with the US Forest Service and other Federal agencies and with state and local forestry groups.

SECTION IV: LAND TREATMENT AND SOIL/REGOLITH CONDITIONING MEASURES

SECTION IV: LAND TREATMENT AND SOIL/REGOLITH CONDITIONING MEASURES

Land Treatment Measures

143. Land treatment measures are among the first steps of the project site restoration/improvement plan to be implemented. Recommendations for these measures are made after the interdisciplinary team has completed the problem site evaluation and selected the best approach to reclaim the area under consideration. Land treatments are carried out at the same time some of the soil conditioning measures are performed. These treatment measures help to stabilize the most critical areas and prepare the site for other restoration measures. The immediate objective of land treatment is to stop the contamination from the problem soil area by closing off the potential sources of contamination or mitigating the effects of contaminants already existing. (The word contaminant is used here in a general sense to refer to any material or substance that is considered undesirable and having some environmental impact.) Selection of land treatment is dictated by the site stabilization needs (i.e., the priority needs for restoring the most critical areas) and long-term goals for enhancement of the area. Table IV-1 contains a list of land treatment measures, which represent the best management practice suitable for activities that are potential contaminant sources. Table IV-2 lists treatments that can be effective in controlling or reducing various kinds of contaminants.

144. Land treatment measures in this section refer to the physical manipulation of the land to control the existing and potential contamination sources contributing to the degradation of the area. The following discussion reviews the general aspects of land treatment measures including slope modification; water handling; and the excavation, substitution, and burial of undesirable materials.

Slope modification

145. Slope stability problems are affected by the degree of slope angle. The type of soil is the limiting factor as to how steep a particular slope can be and still maintain its stability. Slopes steeper than the angle of repose will slough off and prevent effective establishment of vegetation. Too steep a slope also prevents the use of equipment to plant or maintain

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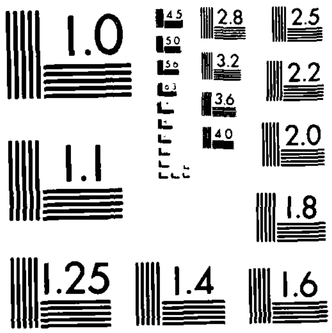
PROBLEM SOIL MATERIA..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR.. C R LEE ET AL.
UNCLASSIFIED MAY 85 WES/IR/EL-85-2 F/G 2/4 NL



MICROCOPY RESOLUTION TEST CHART

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Table IV-1

Land Treatment Measures Related to Potential Contaminant Sources*

Land Treatment Measure	Potential Contaminant Source											
	Stream-banks and Channels	Riparian Zones	Problem Erosion Areas	Crop Production	Irriga-tion and Drainage	Ground Water Infiltration	Trans-portation	Waste and Runoff Water	Airborne Sediments	Silvi-culture	Grazing	Hay and Pasture
Erosion and sediment control structures	X	X	X	X	X		X	X		X		X
Debris basins	X	X	X				X	X		X		
Terrace basins			X		X		X	X			X	
Level spreader			X					X			X	
Sediment barrier		X	X				X	X				
Crushed stone and gravel mulch	X	X	X				X		X	X		
Runoff interceptor trench			X					X		X	X	
Diversion dike	X	X	X			X	X	X		X	X	X
Diversion dam	X	X		X	X							X
Floodwater diversion	X	X	X	X	X		X	X				X
Floodwater retarding structure	X	X					X	X				
Filter strip	X	X	X	X	X					X		
Impervious seals					X	X						
Floodway		X		X				X				X
Planned grazing systems	X	X	X								X	
Proper grazing use	X	X	X								X	X
Waterspreading					X	X					X	X
Chiseling and subsoiling				X		X			X			

(Continued)

* Adapted from Nevada State Conservation Commission (no date).

Table IV-1 (Concluded)

Land Treatment Measure	Potential Contaminant Source											
	Stream-banks and Channels	Riparian Zones	Problem Erosion Areas	Crop Production	Irriga-tion and Drainage	Ground Water Infiltration	Trans-portation	Waste and Runoff Water	Airborne Sediments	Silvi-culture	Grazing	Hay and Pasture
Soil amendment, fertilizer, and pesticide management			X	X						X	X	X
Grassed waterways and outlets			X	X			X	X			X	X
Dust control			X	X			X		X	X		
Water storage reservoir	X	X		X	X							
Salinity control		X		X	X	X						
Stream stabilization	X	X	X									
Water conveyance				X	X	X	X	X				X
Siltation berm		X	X				X	X		X		

Table IV-2

Interactions Between Land Treatment Measures and Contaminants*

Land Treatment Measure	Contaminant: Sediments (Suspended Solids)	Nutrients	Biocides	Organic (Biochemical Oxygen Demand)	Salinity (Dissolved Solids)	Coliform and Pathogens	Thermal	Trash and Debris	Acidity and Alkalinity (pH)	Metals	Other Chemicals
Erosion and sediment control structures	X				X						
Debris basins	X	X						X			
Terrace basins	X	X									
Level spreader	X										
Sediment barrier	X										
Crushed stone and gravel mulches	X				X						
Runoff interceptor trench	X										
Diversion dike	X										
Diversion dam	X										
Floodwater diversion	X				X			X			
Floodwater retarding structure	X				X			X			
Filter strip	X	X	X	X	X						
Siltation berm	X										
Impervious seals		X	X	X	X	X	X		X	X	X
Floodway	X				X			X			
Planned grazing systems	X				X						
Proper grazing use	X				X						

(Continued)

* Adapted from Nevada State Conservation Commission (no date).

Table IV-2 (Concluded)

Land Treatment Measure	Contaminant: Sediments (Suspended Solids)	Nutrients	Biocides	Organic (Biochemical Oxygen Demand)	Salinity (Dissolved Solids)	Coliform and Pathogens	Thermal	Trash and Debris	Acidity and Alkalinity (pH)	Metals	Other Chemicals
Waterspreading	X				X						
Chiseling and subsoiling	X				X						
Soil amendments, fertilizers, and pesticide management		X	X	X				X	X	X	X
Grassed waterways and outlets	X				X						
Dust control	X			X					X	X	X
Water storage reservoir	X										
Salinity control					X						
Stream stabilization	X				X						
Water conveyance	X	X	X	X	X	X	X		X	X	X

vegetation. Generally, slope angles should not be greater than 3:1 (see Figure IV-1).

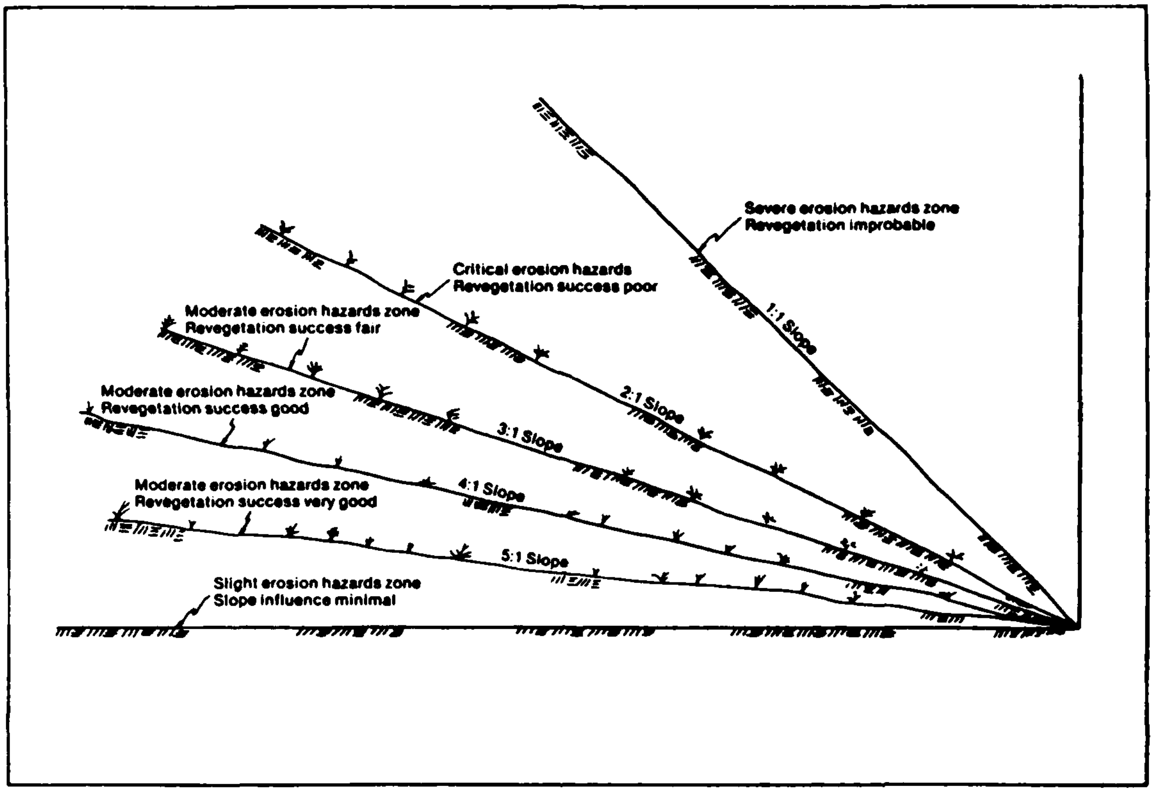


Figure IV-1. Influence of percent slope on revegetation (Nevada State Conservation Commission, no date)

146. Slope length is also important to its stability. Long unbroken slopes allow surface runoff to accelerate and produce rill and gully erosion. Soil losses will increase 1.5 times as the slope length is doubled assuming conditions of soil permeability, texture, organic matter, and erodibility remain equal. A number of slope reduction measures, such as diversions and benches, are illustrated in Figure IV-2.

147. Grading and shaping operations can create areas for water to collect for recreational or wildlife uses or to meet the needs of a particular land management objective.

> Most land uses demand a specific range of topographic slope in order to be economically and/or environmentally feasible. Operations and maintenance are dependent upon gradient. Slopes under 3% allow the greatest number of options and are most suited for intensive activities. Slopes between 3% and 10% are

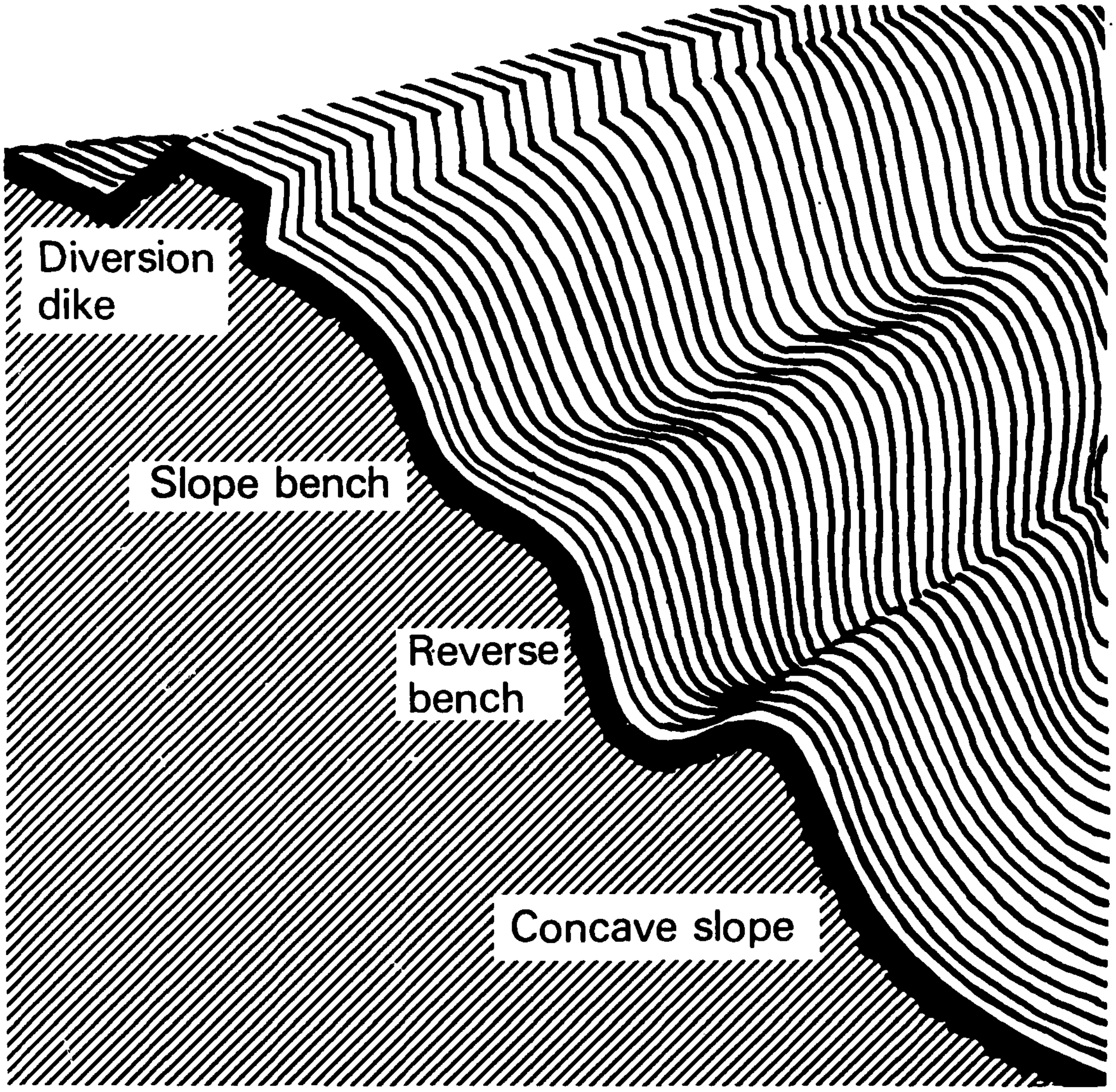


Figure IV-2. Slope reduction measures
(USEPA 1976)

suitable for informal movement and activities. Slopes over 10% are considered steep and are usually not actively used unmodified, except as range or timber production. Slopes under 1% don't drain well; they are associated with wetlands and in arid areas develop concentrations of soluble salts. Slopes over 50% (2:1) seldom have an economic use but provide valuable open space essential to the well being of people, the separation of intensive land uses, reference points, defining edges, habitat for wildlife, and maintenance of ecological stability. Constructed slopes exceeding 50% erode readily unless protected with berming and special drainage swales (American Society of Landscape Architects 1978).

Table IV-3 identifies suitable gradients for a variety of uses. Slope criteria are subject to regional variations. For instance, mountainous areas require use of steeper slopes more than do rolling piedmont or flat coastal areas.

Table VI-3

Gradients for Site Facilities*

Buildings	0%	Football fields	1%
Softball fields	1%	Paved game courts	1%
Parking areas	1-5%	Minor streets	1-7%
Sidewalks	1-8%	Driveways	1-10%
Paved patios	2-4%	Picnic areas	2-8%
Lawn areas	2-10%	Hiking trails	2-25%
Ground cover areas	2-50%	Swimming beaches	3-4%
		Archery ranges	2-10%
Ski slopes	5-25%	Motor boat launching ramps	17-26%

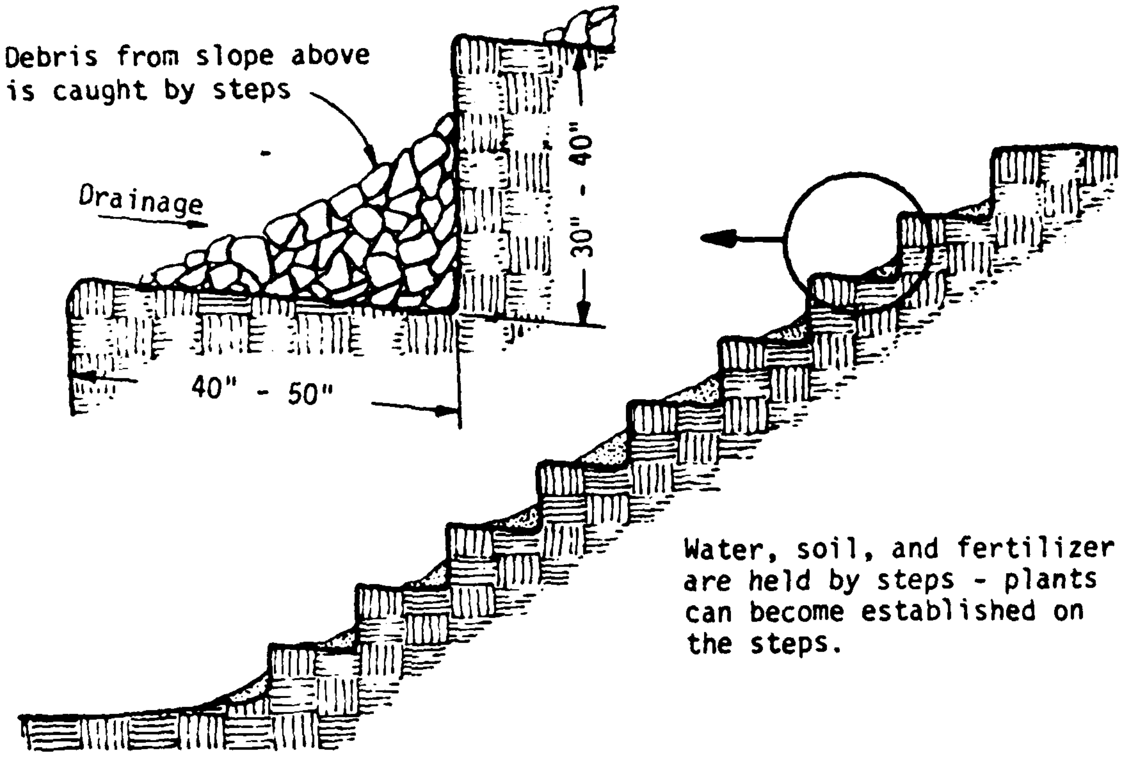
* American Socity of Landscape Architects (1978).

148. Serrated cuts and other surface roughening techniques (Figure IV-3) are slope modifications that provide stability on steep slopes and also collect water to provide a favorable environment for plant growth (See Appendix D for design specifications). This type of modification is not easy to install after a slope has been shaped and graded. It should be used in the initial land treatment. When serrated cuts and surface roughening are used, surface runoff needs to be diverted from the top of the slope.

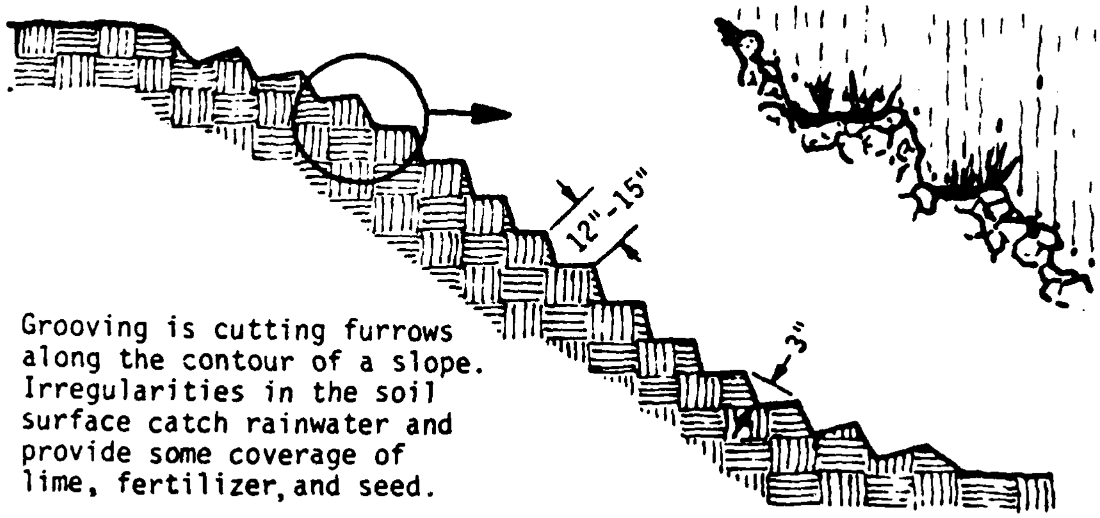
Water handling

149. In humid climates, water-handling structures are required to reduce (or in some situations increase) the amount of runoff generated on the site, prevent offsite runoff from entering the site, or slow the runoff moving through and exiting from the site. Surface water can be managed to:

- Reduce runoff volume and velocity.
- Intercept and divert the runoff.
- Handle and dispose of concentrated flows.
- Conserve and distribute water.



Stair-Stepping Cut Slopes



Grooving Slopes

Figure IV-3. Examples of serrated cuts (Virginia Soil and Water Conservation Commission (VSWCC) 1980)

150. Reduction of runoff volume and velocity. As slope steepness increases, there is a corresponding rise in the velocity of surface water runoff, which, in turn, results in greater erosion. Long, unbroken slopes and roads allow surface runoff to build up and concentrate in narrow channels, producing rill and gully erosion. The rate of runoff and, thus, the rate of soil erosion can be controlled by manipulating the gradient and length of slope using the methods previously discussed. Land-grading techniques such as benches (Figure IV-2) reduce the length, and sometimes steepness, of slopes. Appendix D contains design and construction specifications for some of these practices. Provisions for reducing runoff velocities on roads include use of a cross-dip, waterbar, and waterbreak (USDA, Forest Service 1975).

151. Interception and diversion of runoff. The water handling structures discussed here are used to intercept surface water runoff before it can cause damage, divert collected flow away from critical areas, and discharge collected runoff in suitable disposal areas. Structures used to collect and convey runoff are generally referred to as diversion structures. Diversion structures serve to:

- Prevent surface runoff from higher undisturbed or stabilized areas from coming in contact with exposed soil surfaces.
- Conduct onsite water away from critical areas such as steep slopes, highly erodible soil, landslide-prone areas, and disposal areas for toxic spoil and wastes.
- Prevent sediment-laden runoff from an exposed slope from leaving the restoration site without first passing through a sediment detention structure.

152. Typical diversion structures are dikes, swales or ditches, or a dike and ditch combination (Figure IV-4). Diversion dikes are ridges of compacted soil placed above, below, or around a disturbed area. Diversion swales are excavated, temporary drainageways used above and below disturbed areas. Diversions are permanent or temporary drainageways constructed by excavating a shallow ditch along a hillside and building a soil dike along the downhill edge of the ditch with the excavated soil. Appendix D contains information on the design, construction, and use of various types of diversion structures. They must be designed and constructed to carry the intercepted runoff at nonerosive velocities.

153. Handling and disposal of concentrated flows. In handling concentrated water flows the primary goals are to control its distance, decrease its

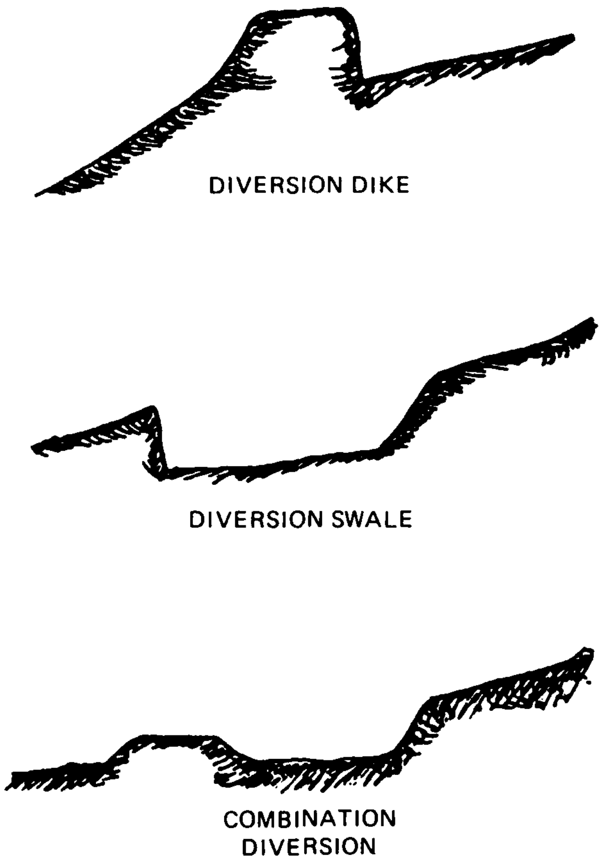


Figure IV-4. Diversion structures for intercepting runoff

gradient, and obstruct the flow. Flow distance may be controlled by lengthening drainageways. However, care must be taken to ensure that the resulting flow will not erode or overflow in the channel. Flow gradient can be controlled through the placement of check dams and other flow control structures across the channel. Grade control structures also serve to obstruct flow within the channel, and, as a result, slow its movement. Placement of the water handling structure nearly parallel to the ground contour is a means of controlling the gradient and maximizing the flow distance. Again, care must be taken to ensure that the channel can carry the design flow without overtopping in critical areas such as along erodible slopes. See Appendix D for design and construction specifications of selected structures.

154. Materials such as rock riprap placed in the channel will dissipate the energy of the flow. This will also reduce the ability of the concentrated flow to cause erosion. Energy dissipators should be placed below grade

control structures and outfalls, and, when necessary, along the outside of channel bends. Further information on the design of energy dissipators can be found in the Federal Highway Administration's Hydraulic Engineering Circular No. 14 (1975).

155. Structures used to control concentrated flow include downdrain structures (paved chute or flume and the pipe slope drain) and waterways. Paved chutes, or flumes, are channels extending from the top to the bottom of the slope and lined with nonerodible material such as bituminous concrete, portland cement, or grouted riprap. Pipe slope drains may be rigid pipe or flexible tubing, connected to a prefabricated inlet section. They are considered temporary measures and also extend from the top to the bottom of a slope. Design and construction specifications are presented in Appendix D.

156. Waterways are stabilized channels designed to safely handle the anticipated flow rate. Channel linings vary according to flow rates. Grade control structures and energy dissipators are also used to stabilize the channel for high-velocity water flow. Design and construction specifications are presented in Appendix D. Table IV-4 lists the various channel linings that can be used and some remarks on their use and maintenance.

157. Each water control structure must have a stable outlet. The outlet may be a natural drainageway, vegetated area, or other stable watercourse. In all cases, the outlet must convey the water without incurring erosion. Disposal of small flows in upland areas can be performed using a level spreader. The structure is a well-stabilized outlet constructed at zero percent grade (along the outlet lip) which converts concentrated flow into less-erosive sheet flow. The flow is discharged onto a vegetated slope in an area where the water will not be reconcentrated immediately below the structure. A figure and design specifications for the level spreader are located in Appendix D.

158. Impoundment structures may also be used to control runoff by trapping sediment from the site and reducing downstream channel erosion and flooding problems. Trapping sediment is their primary function. However, when increased runoff is expected, offsite erosion and flooding potential should also be given careful consideration in the design and construction of water detention or impoundment structures. Impoundment structures such as sediment basins detain runoff and release it at a controlled rate. Thus, the ability of the inflowing water to carry sediment is reduced, suspended particles

Table IV-4

Waterway Linings*

Type	Remarks	Maintenance
Grassed (further information on grasses is located in App. D, Fig. D-56)	Need to divert water to establish vegetation	Fertilize
	Lime, fertilize, seed and mulch	Mow at height of 4 to 6 in. and at least two times per year to prevent thatching of grass. Do not mow unless waterway will support equipment. (Waterlogged soils in spring should be avoided)
	Methods of keeping seeds and seedlings on steep slopes (using cloth, latex spray, chemical tacks, etc.) are discussed in Section VI	
	Cut mulch at 90° to line of flow with rolling cultipacker	Rotor mower preferable to sickle bar mower
Channel liner	Used for channel with occasional water flow which cannot be diverted	Routine inspection and replacement if necessary
	Erosion checks of fiberglass: 50 ft apart on sandy soils, 100 ft apart on heavier soils, and at gradient changes	
	Erosion checks must be flush with surface	
	Paper netting at sites with little flow	
	Installation by experienced persons only	
Low-flow channel	Riprapped subgraded ditch for constant flow (spring, seepage, etc.)	
	Grass on waterway sides	

(Continued)

* In order of increasing flow velocity handling capacity.

- Environmental requirements for control of:
  - Erosion and sediment.
  - Water quality.
  - Air quality (dust and noise).
  - Special conditions (e.g., use of explosives).
- Advantages and disadvantages of various alternative soil treatments versus no treatment.
- Maintenance of:
  - Equipment and vehicles.
  - Ditched areas.
  - Subsurface drains.
  - Other.
- Monitoring (if required):
  - Soil/regolith physical properties.
  - Soil/regolith hydraulic properties.
  - Soil/regolith chemical properties.

178. All of the above items are site-specific; therefore, the detailed environmental provisions must be based on the findings and recommendations of the interdisciplinary survey team.

179. Soil conditioning measures that have promise with respect to various problem soil materials are identified in this section. Potential soil conditioning measures are summarized in Table IV-6. The specific combination of soil treatment measures that is selected by the interdisciplinary team should reflect the assigned restoration priority rating and the apparent similarities and differences between the six types of construction activities that usually occur at project sites. For example, borrow areas qualify as sidehill-type excavations partially resembling cut slopes, but differing from highway cut slopes by having a level floor partially surrounded by cut slopes (Blauch 1978). Thus, borrow areas require potentially different land treatments than highway cut slopes, and, generally, they require somewhat different approaches to their restoration. Similar analyses and comparisons must be made between excavated material disposal sites (EMDS) and fill slopes, and between semi-improved and unimproved sites.

180. The use of soil conditioning measures usually entails considerable expense. Therefore, with the exception of those measures that are widely accepted as being successful (e.g., those used on problem sites containing dispersive clays and those having excessive internal drainage), it is imperative that evaluations be made to ascertain if all other soil conditioning measures purported to have promise will, in fact, meet the restoration needs of a given

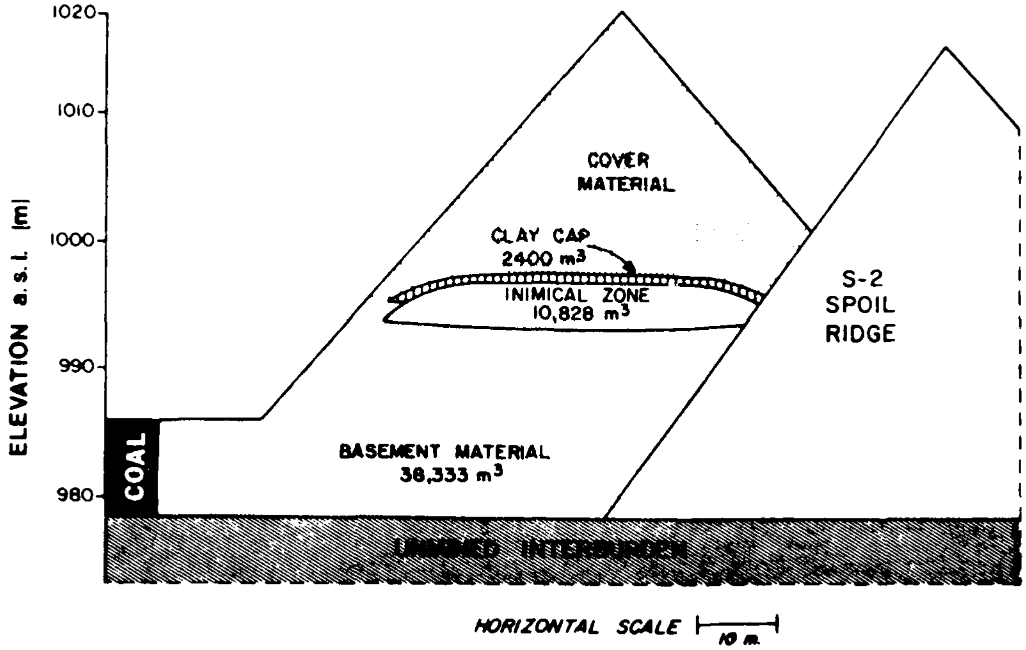


Figure IV-5. Transverse cross section of a cap at a Western mine site

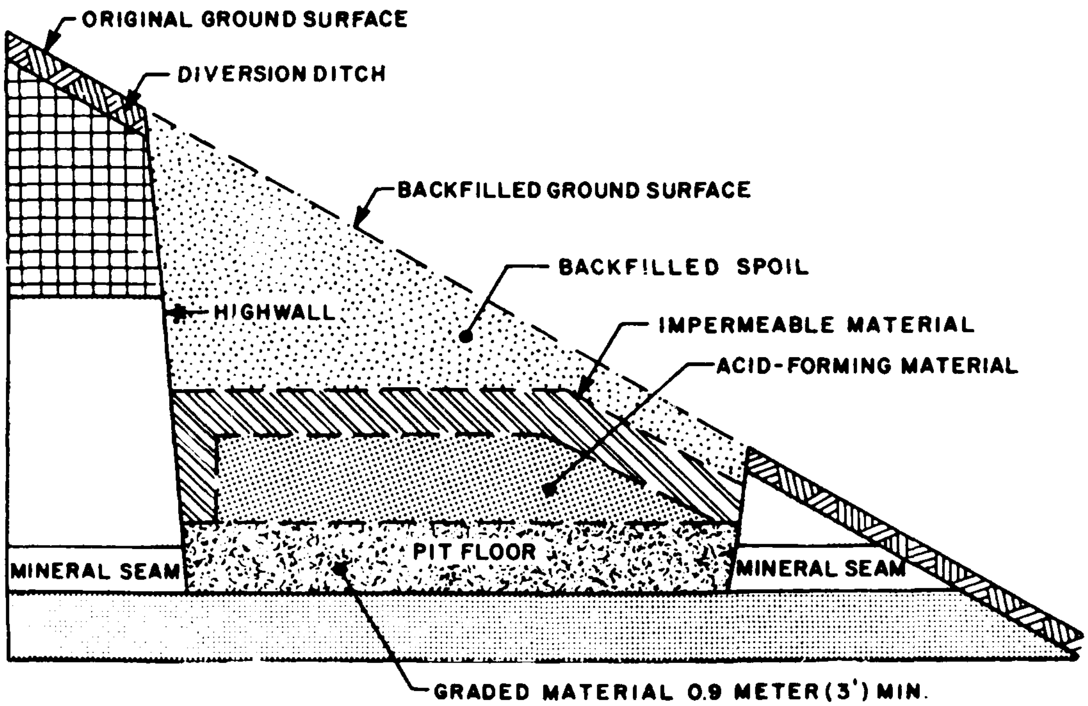


Figure IV-6. Proper placement for burial of acid forming material at a mine site (USEPA 1980)

maximum compaction. The American Society of Testing and Materials has published and designated this procedure as D69E.

175. In constructing the cap, it is perferable to form the clay over the materials to ensure that percolating soil moisture is effectively diverted around the buried material (Figures IV-5 and IV-6). This "umbrella-effect" is accomplished by grading the materials to a 5:1 slope in all directions before placement of the capping materials.

Soil/Regolith Conditioning Measures

176. Soil/regolith conditioning measures are defined as physical, chemical, and/or biological treatment that is applied to critical areas in advance of the establishment of vegetation. Control of soil erosion is the paramount concern (USEPA 1973b; Transportation Research Board 1973; State of Maryland, Department of Natural Resources 1972; Glover, Augustine, and Clar 1978; USDA, SCS 1978, 1979b; and South Dakota State Conservation Commission, no date).

177. The specifications writer should develop appropriate schedules and specifications for incorporating the approved soil conditioning measures into the construction specifications. These specifications should qualify as Detailed Environmental Provisions (DEP), as defined by the Construction Engineering Research Laboratory (CERL) (Riggins 1975; Riggins et al. 1975). The DEP prepared by the specifications writer shall include the following items:

- Definition of the objectives of the various soil/regolith conditioning measures.
- Specifications of all essential soil tests as required for specific problem soil materials.
- Specifications of specialized and conventional equipment required to carry out the soil/regolith conditioning measures.
- Specification of all application materials.
- Identification of relevant constraints to use of the soil/regolith conditioning measures (e.g., time factors and environmental quality considerations).
- Significant exclusions pertaining to:
  - Order of soil/regolith treatments.
  - Depth of applications of various soil amendments.
  - Related incompatibilities.

171. Evaluation of cap thickness. Minimum cap thickness requirements will vary in accordance with the previous experience of the various states. Cap thicknesses in excess of various state requirements will be determined by (a) surface relief; (b) water infiltration properties of the coverage (i.e., as controlled by gravity and capillary processes and by surface mulch); (c) oxygen diffusion rate into the coverage; (d) freeze/thaw or shrink/swell effects; (e) future support and/or trafficability requirements planned for the disposal area; (f) vegetative cover requirements (based on planned future land uses, etc.); and (g) inherent potential for development of fissures, piping, and deep cracks (Lutton 1980).

172. A general expression describing the adequacy of cap thickness was offered by Lutton (1980) as follows:

$$T \geqq 2R \tag{1}$$

where

T = cover thickness

R = vertical distance from high point to low point of irregularities on top of the disposal site

According to Lutton (1980),

> ...the size of the area over which this vertical distance should be measured corresponds roughly to the size of the equipment used for placing closure cover. Where intermediate size dozers are to be used, the area within which the relief is measured would be on the order of 20 by 20 feet. In large covering operations where pans or other large pieces of equipment are to be used, the area size could be on the order of 50 feet across.

173. Other details for evaluating cap thickness are given in Lutton, Regan, and Jones (1979, Chapters 8 through 23) and McAneny et al. (in preparation). It appears that the best cap material for use at disposal sites containing pyritic material is relatively impermeable inorganic clay soil (see Table IV-5) because of its ability to impede water percolation and oxygen diffusion in soil around the buried pyritic materials, thereby impeding sulfuric acid production.

174. Location of clays suitable for use as capping material should be noted during the site evaluation process. The moisture-density relationship of the clay should be determined to indicate the optimum moisture content for

d. Control wind erosion by:

- Quickly establishing suitable herbaceous vegetative cover (i.e., sufficient mature height to dissipate high winds).
- Using wind breaks consisting of shrubs and trees.
- Choosing favorable designs for disposal areas such as orientation away from prevailing winds and proper length/width configurations.
- Choosing coarse soil/forming soil clods resistant to high winds.
- Minimizing knoll-like surface configurations.

e. Stabilize slopes by:

- Keeping slope inclination at 1:4 or less.
- Providing for seepage control or drainage.
- Providing vegetative cover.
- Using the trench method in special cases.
- Compacting fill slopes to specifications.

f. Reduce effect of freeze/thaw and dry/wet cycles by:

- Using coarse granular soils for cap materials.
- Using conventional organic mulches atop seedbed.
- Scheduling operations on a seasonal basis.

169. The rate of oxidation (breakdown) of pyritic and other sulfide materials and the rate of production of sulfuric acid are controlled by absolute amount of pyrite and by grain size. Thus, the smaller the grain size, the more reactive is the pyrite (Bradshaw and Chadwick 1980). Finely divided materials with a relatively low pyritic sulfur level (0.8 percent) were found to produce sulfuric acid at the same rate as materials with pyritic sulfur at 3.7 percent during a 50-day period. The best approach in assessing the potential rate of acid production appears to be to first determine the content of pyritic sulfur, and then to multiply this value by the percentage of reactive pyrite in the material. These tests, however, are time-consuming (Bradshaw and Chadwick 1980). Further details on pyrite test methods can be found in Appendix H.

170. The negative effect of sulfuric acid on soils is the solubilization of aluminum, which at low concentrations is extremely toxic to plant roots. Additional problems arise from the interaction of sulfuric acid with soil carbonates to form sulfates of calcium, magnesium, and sodium which in turn increase salinity (Bradshaw and Chadwick 1980).

Table IV-5 (Concluded)

USCS Symbol	Stability	Side Slope Seepage	Drainage	Discourage Burrowing	Impede Vector Emergence	Discourage Birds	Support Vegetation	Future Use: Natural	Future Use: Foundation
GW	Determine on basis of laboratory testing	Same ranking and values as for Impede Water Percolation	Same ranking and values as for Assist Water Percolation	Same ranking and values as for Slipperiness Trafficability	X	All soils are suitable	X	Same ranking as for Support Vegetation	Same ranking and values as for Go-No Go Trafficability
GP					X		X		
GM					VIII		VI		
GC					V		V		
SW					IX		IX		
SP					IX		IX		
SM					VII		II		
SC					IV		I		
ML					VI		III		
CL					III		VII		
OL					VI		IV		
MH					II		IV		
CH					I		VIII		
OH					--		VIII		
Pt					--		III		

(Sheet 3 of 3)

Table IV-5 (Continued)

USCS Symbol	Fire Resistance	Erosion Control: Water (K-Factor)*	Erosion Control: Wind (Sand-Gravel, %)	Dust Control	Reduce Freeze Action: Fast Freeze (H_c, cm)*	Reduce Freeze Action: Saturation (Heave, mm/day)	Crack Resistance (Expansion, %)
GW	Same as Impede Gas Migration	I (<0.05)	I (95-100)	Same ranking and values as for Wind Erosion Control	X	I (0.1-3)	I (0)
GP		I --	I (95-100)		IX	I (0.1-3)	I (0)
GM		IV --	III (60-95)		VII	IV (0.4-4)	III --
GC		III --	V (50-90)		IV	VII (1-8)	V --
SW		II (0.05)	II (95-100)		VIII	II (0.2-2)	I (0)
SP		II --	II (95-100)		VII	II (0.2-2)	I (0)
SM		VI (0.12-0.27)	VI (60-95)		VI	V (0.2-7)	II --
SC		VII (0.14-0.27)	VI (50-90)		V	VI (1-7)	IV --
ML		XIII (0.60)	VII (0-60)		III	X (2-27)	VI --
CL		XII (0.28-0.48)	VIII (0-55)		II	VIII (1-6)	VIII (1-10)
OL		XI (0.21-0.29)	VII (0-60)		--	VIII --	VII --
MH		X (0.25)	XI (0-50)		--	IX --	IX --
CH		IX (0.13-0.29)	X (0-50)		I	III (0.8)	X (>10)
OH		VIII --	--		--	--	IX --
Pt		V (0.13)	--		--	--	--

(Continued)

(Sheet 2 of 3)

Table IV-5

Ranking of Unified Soil Classification Scheme (USCS) Soil Types According to Performance of Cover Functions*

USCS Symbol	Typical Soils	Go-No Go (RCI Value)**	Trafficability: Stickiness (Clay, %)	Trafficability: Slipperiness (Sand-Gravel, %)	Water Percolation: Impede (k, cm/sec)**	Water Percolation: Assist (k, cm/sec)**	Gas Migration: Impede (H_c, cm)**	Gas Migration: Assist (H_c, cm)**
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	X (10^{-2})	III	X (6)	I
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	XII (10^{-1})	I	IX --	II
GM	Silty gravels, gravel-sand-silt mixtures	III (177)	III (0-20)	III (60-95)	VII (5×10^{-4})	VI	VII (68)	IV
GC	Clayey gravels, gravel-sand-clay mixtures	V (150)	VI (10-50)	V (50-90)	V (10^{-4})	VIII	IV --	VII
SW	Well-graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	IX (10^{-3})	IV	VIII (60)	III
SP	Poorly graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	XI (5×10^{-2})	II	VII --	IV
SM	Silty sands, sand-silt mixtures	II (179)	IV (0-20)	IV (60-95)	VIII (10^{-3})	V	VI (112)	V
SC	Clayey sands, sand-clay mixtures	IV (157)	VII (10-50)	VI (50-90)	VI (2×10^{-4})	VII	V --	VI
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	IX (104)	V (0-20)	VII (0-60)	IV (10^{-5})	IX	III (180)	VIII
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	VII (111)	VIII (10-50)	VIII (0-55)	II (3×10^{-8})	XI	II (180)	IX
OL	Organic silts and organic silty clays of low plasticity	X (64)	V (0-20)	VII (0-60)	--	--	--	--
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	VIII (107)	IX (50-100)	IX (0-50)	III (10^{-7})	X	--	--
CH	Inorganic clays of high plasticity, fat clays	VI (145)	X (50-100)	X (0-50)	I (10^{-9})	XII	I (200-400+)	X
OH	Organic clays of medium to high plasticity, organic silts	XI (62)	--	--	--	--	--	--
Pt	Peat and other highly organic soils	XII (46)	--	--	--	--	--	--

Same k values as for Impede Water Percolation

Same H_c values as for Impede Gas Migration

(Continued)

Note: The ratings I to XIII are for best through poorest in performing the specified cover function.

* Lutton (1980).

** RCI is rating cone index; k is coefficient of permeability; H_c is capillary head; and K-Factor is the soil erodibility factor.

(Sheet 1 of 3)

- Slope stability characteristics.
- Susceptibility to wind erosion, especially in arid and droughty climates.
- Trafficability and support requirements.
- Freeze/thaw and swell/shrink effects.
- Projected use for landfill/disposal area(s) [e.g., especially important where buildings and parking areas will be placed atop the disposal area but not as important where future use will be a tree farm or wild area (see Lutton, Regan, and Jones 1979 and Lutton 1980)].

168. Pertinent recommendations for specific design elements and the choice of cap materials are summarized below, based on Lutton, Regan, and Jones (1979):

a. Impede infiltration/percolation by:
   - Increasing thickness of cap.
   - Using barrier membranes.
   - Compacting soils sufficiently (with special compacting equipment).
   - Using chemical soil additives.
   - Mixing soils well to avoid permeable zones.
   - Increasing surface slope and developing a ditch system.

b. Impede gaseous diffusion by:
   - Using fine-textured cap materials (e.g., inorganic clays).
   - Maintaining high moisture holding capacity (e.g., soils having high field capacity).

c. Control water erosion by:
   - Establishing temporary grass-legume vegetative cover (as necessary).
   - Establishing long-term, low maintenance grass-legume covers.
   - Providing mulch cover atop seeded mixtures.

   Applying chemical tacks to mulch cover.
   - Specifying soil compaction needs.
   - Using soil covers having moderate to high resistance to water erosion based on the universal soil loss equation (USLE).

will increase as the weight of equipment passing over it is increased and as the number of passes of that equipment is increased.

165. A cap should be placed around the buried undesirable materials so as to create an impervious barrier to water migrating upward or downward, thus inhibiting the movement of undesirable ions from the material. Caps can be made of clay or other soil materials. An impermeable clay layer, however, provides the best protection and has been successfully used at mining sites in the East and West. Under extremely dry soil conditions, clay layers can crack and potentially allow water penetration.

166. Capping undesirable materials. The focus of this discussion is on the pyritic, sulfur-containing, subsurface geologic materials which, if not quickly buried deep, will generate copious amounts of sulfuric acid. Quick burial is a cost-effective way to limit the interactions between pyritic sulfides, oxygen (air), and soil moisture to form levels of sulfuric acid that are harmful to plant roots and other living organisms (aquatic and terrestrial). For example, there are numerous examples where acid has drained from unburied pyritic materials into high-value streams, with drastic damage to gamefish and their food supply.

167. Since the burial or treatment of sulfide-containing geologic materials must be done quickly after being unearthed, it is essential that provision is made for systematic evaluation of core sampling data by the stage one reconnaisance survey team assigned to the project site (see Section III, Table III-3 and accompanying text). In addition to these observations, the stage one survey team should:

a. Document the volume, acreage, location, and physical properties of each of the major soil types (see Table IV-5 for rankings of soils for use as caps).

b. Evaluate soils and geologic materials relative to the following key parameters:

- Suitability for capping disposal site.
- Susceptibility to impedance of eventual percolation/infiltration rates.
- Likelihood of impedance of eventual diffusion rates for air and other gases.
- Susceptibility to piping and/or development of fissures and deep cracks.

Excavation, substitution, and
burial of undesirable materials

162. Analysis of core samples and soil sampling data by the interdisciplinary team during the site evaluation process may indicate the presence of deposits of materials possessing undesirable chemical or physical properties such as sulfides and dispersive clays. Based upon this evaluation, the specifications writer should make provision in the restoration plan for the excavation, substitution, and burial of these materials. The specifications need to recommend a suitable burial site, determine the method of burial, and locate suitable soil/regolith materials for filling the void left after removal of the contaminated soil. Hazardous wastes cannot be disposed of in landfills. An approved burial site should be as near the excavation site as possible to reduce haul cost.

163. Another concern is that undesirable materials be placed high enough to be out of the ground-water zone. Knowledge of ground-water conditions at the CWP site is critical to avoid contamination of ground-water supplies. This is especially important in the arid and semiarid regions where inhabitants are highly dependent on ground-water resources for agricultural, industrial, and municipal water supplies.

164. Placement of undesirable materials should be in controlled layers. The following questions should be considered when these materials are involved:

- Is compaction of soil materials required to increase the storage capacity of the disposal site?
- Should placement be controlled to limit leachates?
- Will elimination of settlement be important to abandonment and future land use?
- If the present development plans for the disposal site were later modified, could the area become critical in the new plans?

Uncompacted fills tend to settle under the weight of traffic, and with time and weather. Placement in the thinnest layers practical with some compaction will minimize air and water infiltration and reduce settlement. Compaction by planned routing of the hauling and placing equipment may also be adequate when layers are thin. The lift thickness used at any given site should be based on the characteristics of the earth materials and the method of compaction. Thin lifts will be required if compaction is to be accomplished by the movement of light hauling units and spreading equipment. The acceptable lift thickness

area to plant-growing zone; these ratios can range as high as 30:1.

Generally, if the plant materials specialist consistently observes pools of water or gullies originating in the plant-growing zone, the water-collection area may be too large. Preferably, the moisture accumulated will readily absorb into the plant-growing zone.

A variety of methods are available for water harvesting. The object in using any of these methods is the same, however: to increase runoff from the water-collecting zone and increase infiltration in the plant-growing zone.

Long water-collection beds work satisfactorily only on areas where the terrain is flat. The water collected in long beds on steep slopes will not be distributed evenly onto the plant-growing zone. Caution should be exercised when considering the use of contour trenches on soils that tend to settle or soils that are subject to piping as this might cause slope failures or increased erosion due to water concentration.

Various chemical treatments, including paraffin, silicone emulsion, and polyvinyl acetate, have been used to prevent penetration of water into the water-collection area and thus to increase the amount of water running off into the plant-growing zone. Some of these additives will also aid in stabilizing the water-collection zone's surface. The decision to use a chemical sealing material should be based on the soil characteristics of the site being used as a water-collection zone. For example, if the soil is a high sodic clay type, it tends to seal itself and thus the addition of a chemical sealant does not increase water runoff. In these cases, the cost of using that chemical is not justified.

On the other hand, if the soil is a sandier type, reducing infiltration by using a chemical sealant is important. In these cases, a 25-percent greater plant establishment has been reported on treated areas as compared to non-treated areas.

Mulching will aid in water harvesting because it will improve infiltration and reduce evaporation in the plant- growing zone. Noticeable results have been achieved by using a vertical mulch, which is a method of gouging a narrow slit in the ground near the plants and crimping straw into it to increase infiltration. In addition, both straw and bark have been successfully used as a mulch.

settle out of suspension, and the peak rate of flow in the downstream waterway is reduced. Basins are normally designed to store a 10-year frequency runoff event. Most basins are equipped with a perforated riser pipe that allows the stored water to be released at a controlled rate following a storm. When a permanent pool (wet) basin is constructed, additional storage capacity is provided.

159. Conservation and distribution of water. In arid and semiarid areas, conservation and distribution of water for vegetative establishment are essential. Waterspreading and water harvesting are techniques used for these purposes.

160. Waterspreading diverts runoff from natural channels or gullies through a system of dams, dikes, or ditches, and spreads it over relatively flat areas. Waterspreading provides extra moisture and disperses floodwaters to reduce sediments and damage to watershed areas. Design, construction, and maintenance information can be found in Appendix D.

161. The following discussion on water harvesting has been excerpted from the US Department of Agriculture, Forest Service (1979b).

> Water harvesting is the practice of using the landscape to collect and accumulate runoff water of acceptable quality and concentrate that moisture in a plant-growing zone. Water harvesting is appropriate in areas that receive less than 15 inches of precipitation annually; it is also useful in any spot where rainfall is the major limiting problem associated with revegetation, and irrigation water is scarce. Snow and rain will both be trapped by water harvesting methods. The results can be 2 to 3 times more biomass growth from plants exposed to water harvesting than from those that are not exposed to this technique.
>
> Various methods of shaping the land result in water harvesting. The area to be set aside for collecting water varies, depending on rainfall amount, intensity, and timing, as well as soil infiltration and slope. For example, if rainfall amounts and intensity are high, a smaller area will be needed as a water-harvesting zone because water runoff will be substantial. In addition, if the infiltration rate of the water-collection site is low, a smaller water-collection area will be needed to get the necessary runoff. These factors will help the plant materials specialist determine the ratio of water-collection

Table IV-4 (Concluded)

Type	Remarks	Maintenance
Low-flow channel (con't)		
	Jute or Enkamat liner	
Riprap	Use filter-x for soils with poor structure or seepage areas with settling to keep uniform gradient of stone	Remove bridges or obstructions created by foreign objects to avoid ponding
	For when either low-flow channel or entire channel is riprapped	Check for loose stones from frost heave in spring
Mattress (Maccaferri)	Use when riprap is being carried away by flow	Requires least maintenance and has longest life of all linings
	Flexible for lining channel	Soil will eventually cover mattress and waterway will revegetate
	Use filter-x underneath mattresses	
	Gabions and weirs used for de-energizing	
	Recommended in place of riprap where removal of stones by public is potential problem	
	Plastic-treated mattress needed where water contains salt or caustic materials	
Concrete	Monolithic reinforced	Check for water underneath channel
	Energy dissipators needed	Check for voids under and around channel
	Not suitable for acid flow	Watch for undermining from seepage underneath waterway
	Not recommended for critical areas	
	Expensive, last resort	

Table IV-6

Summary of Potential Soil Conditioning Measures Applied in Advance of Customary Seedbed Preparation

Measure	Problem Soil Material (Primary Use) Acid	Saline	Sodic	Excessively Drained	Poorly Drained	Dispersive Clays	Wind Erodible
Physical							
Contour ridge/ravine	X						X
Soil platings	X			X			
Sand and gravel blanket		X				X	
Multidepth ripping	X		X				X
Slope modification/grading	X		X	X		X	X
Leaching with calcium salts		X	X				
Surface microrelief (land imprinting, gouging, etc.)	X	X	X			X	X
Subsurface drainage	X		X				
Snow fence and related structures							X
Water harvesting and spreading		X	X	X			X
Clods/surface roughening							X
Wire fencing to control grazing, etc.		X	X				X
Incorporation of silt plus clay	X			X		X	
Chemical							
Surface incorporation							
Gypsum		X	X				
Iron sulfate			X				
Calcium hydroxide						X	
Ammonium sulfate			X			X	
Ammonium nitrate			X			X	
Basic slag or flyash	X			X			
Deep incorporation of:							
Gypsum		X	X				
Calcium carbonate	X						X
Leaching with calcium salts		X	X				
Biological							
Tree shelterbelts				X			X
Deep incorporation of composted sludge	X			X			X
Tolerant plant materials	X	X	X	X	X	X	X
Standing stubble			X	X			X
Preparatory plantings	X			X			X

site. However, the exception may be based on the simplified (and perhaps unlikely) assumption that the problem to be resolved relates solely to the presence of dispersive clays, and/or to soils with excessive internal drainage. Where doubt arises, the interdisciplinary team has the responsibility of ascertaining that the apparent soil problem is not confounded by other soil limitations at the site. If the available data do not permit a clear-cut decision, the interdisciplinary team should recommend any appropriate action, including the use of greenhouses and field tests, to provide a clear-cut decision. The design of greenhouse and field experiments for evaluating various soil conditioning measures has been amply documented elsewhere (Morrison and Emmons 1977, Foy, Voight, and Schwartz 1980; Huntington, Barnhisel, and Powell 1980; Perrier and Patin 1980; Byrnes, McFee, and Stockton 1980; Lee et al. 1983).

181. Should it be established that detailed site studies must be conducted, the interdisciplinary team shall recommend the use of low-cost, interim treatment measures that will temporarily control contaminant runoff (if needed), pending the analysis of data and decisionmaking relative to the required studies. It should be made clear to the interdisciplinary team that a no-action decision is often possible, especially for those problem soil areas that have evolved (via secondary succession) into habitats considered suitable for wildlife and where their biological potential has been realized.

182. The Corps of Engineers appears to have greater flexibility in the resolution of problem soil area stabilization than do mining, highway, or farming operations. For example, the interdisciplinary team has the option of selecting and fitting the most adaptable plant materials to the problem soil environment, thereby circumventing the extra costs involved in conditioning the problem soils to several more or less demanding plant species, as often practiced on farms and along key highways. On project sites, major emphasis can be placed on the attainment of secondary succession, limited maintenance, and upgraded biological potential in the long term. For example, several shrubs, trees, and ground covers that are known to have broad tolerance to certain problem soil environments (see Section V) could be used.

183. Woody plant materials will not replace the use of adapted grasses and forbs for the initial vegetative stabilization of problem soils. Grasses and herbaceous legumes will remain as the most important group of plant materials for use in the vegetative stabilization of problem soils. But, in the selection of these materials, one must exercise care in choosing species

(e.g., switchgrass and lovegrass) with growth habits that will not interfere with the growth and secondary succession of volunteer woody plants, or the successful establishment, later on, of planted shrubs, trees, and ground covers.

184. Some problem soils absolutely require soil conditioning measures before the establishment of vegetation. For example, dispersive clays sometimes found along waterway and impoundment embankments in Oklahoma and Mississippi must be removed, treated in bulk with hydrated lime, thoroughly mixed, and then put back, en masse, onto the cut or fill slope before revegetation.

185. Another example, though less dramatic, refers to soils that have excessive internal drainage. In this case, it is often necessary to make deep (i.e., to depths of 12 to 24 in.) in situ incorporation (preferably in separate layers rather than mixing together) of composted sludge, soils that contain about 25 percent silt plus clay, or a combination of these and other treatments before revegetation (Power, Sandoval, and Ries 1978). This treatment could also be useful on soil materials contaminated with toxic heavy metals or those having an extremely low pH.

186. Compacted areas can be eradicated using rippers and subsoils. The addition of organic matter will also help prevent further compaction. Traffic on the site, especially from vehicles with tires, should be kept to a minimum.

Land Treatment and Soil Conditioning Measures for Specific Problem Soil Materials

Acid soil materials

187. The selection of land treatment and soil conditioning measures for extremely acid to strongly acid soil materials (pH 2.5 to 4.5) should include measures that are designed to increase the pH level to one that will enable selected plant materials to grow and reproduce over long time periods under limited maintenance. In this discussion, attention is centered on widely recognized or promising measures for correcting the acid soil problem.
Table IV-7 summarizes the materials, equipment, and other considerations that have known value or promise for the conditioning of acid soils. It is likely that several other equally important soil-related problems also may need to be corrected at a given project site. For simplicity of discussion, it is necessary to deal with one problem at a time, but it should be recognized that the

Table IV-7

Materials and Equipment for Conditioning Acid Soils/Regolith

Soil Conditioning Measure	Materials Needed	Equipment Needed	Remarks
1. Excavation of barren soil areas	Topsoil with about 25% silt plus clay (e.g., uncontaminated dredged material)	Ripping gear, with or without deep placement of limestone and fertilizer	Excavate the upper 10 in. or so of barren soil, and then cover excavated area with about 30 in. of nonacid soil having a silt plus clay content of about 25%. Apply limestone about 6 months in advance of final seedbed preparation and seeding
Planting with new soil materials			
Liming	Add limestone to pH 5.5		
2. Contour ridge "ravine" system	Plant material adapted to a soil pH of 4.0 or less	(see Riley 1973)	Survival of acid-loving plants was greatest after 7 years in the "ravines" rather than on the slopes, ridges, or smooth-graded surfaces
Liming	Add limestone to pH 5.5		Deep lime incorporation can be performed in two steps. (1) Spread topsoil to a predetermined thickness and grade properly; avoid excess compaction. (2) Incorporate limestone at a rate sufficient to raise the soil pH to 5.0 and to depths of 15 to 18 in. using a 42- to 50-in. disc harrow
3. Incorporate digested sludge	Sludge	Ripper with attachments	
Composted sludge	Sludge		
Composted garbage	Garbage		
4. Sawdust			
5. Animal manure			

occurrence of other problems that naturally coexist alongside the acid soil conditions can greatly influence the overall combination of soil conditioning and plant selection measures finally selected by the interdisciplinary team.

188. For purposes of discussion, the following two types of acid regolith materials may occur on project sites:

- Pyritic and related sulfide-containing materials having extremely high residual (or total) potential acidity, which upon exposure to air and microorganisms result in the production and release of sulfuric acid. Identification and prevention of exposure to air is the best treatment (see Appendix H).
- Naturally acid sandstone and shale whose acidity stems from the low base (calcium, magnesium) content of the weathered and leached parent (i.e., nonpyritic) material (see Section II).

189. Pyritic and related sulfide-containing materials. Pyrite may be present in black shales in such a dispersed, fine-grained form that it is visible only under a microscope (Vogel and Curtis 1978). This form, if present in sufficient amounts, is considered more potentially reactive that visible pyrite. Thus, all fine-grained strata such as shale and claystone must be carefully examined for pyrite and related acid-forming materials during the site evaluation. Soil samples should be tested according to procedures outlined in Appendix C, Figure C-1. Preconstruction soil borings can also be tested in a similar manner. If pyrite material is present, the location within the soil boring will indicate which material should be isolated and preferably buried during construction of the project to minimize exposure to the atmosphere (paragraphs 162-175).

190. For potentially extremely acid soil materials, after-the-fact land treatment may specifically include the following measures:

- When the volume of seepage from a steep cut slope is extremely high and a slide is likely to occur, benches must be cut into the slope and a subsurface drainage system used to intercept the flow and convey the acid water from the site (Figures IV-7 and IV-8). Subsurface drainage materials should be acid-proof (no metal or concrete). The water table should be lowered sufficiently to provide a suitable rooting zone for vegetation. Design specifications for subsurface drainage are presented in Appendix D.
- When erosion from a seep at a steep cut slope is not too severe, the whole surface of the slope can be riprapped with slag and crushed limestone (i.e., rock mulch). This aids in both erosion control and neutralization of the acid water. Water is collected at the base of the slope and carried from the site. Hydroseeding can take place later over the stabilizing materials.

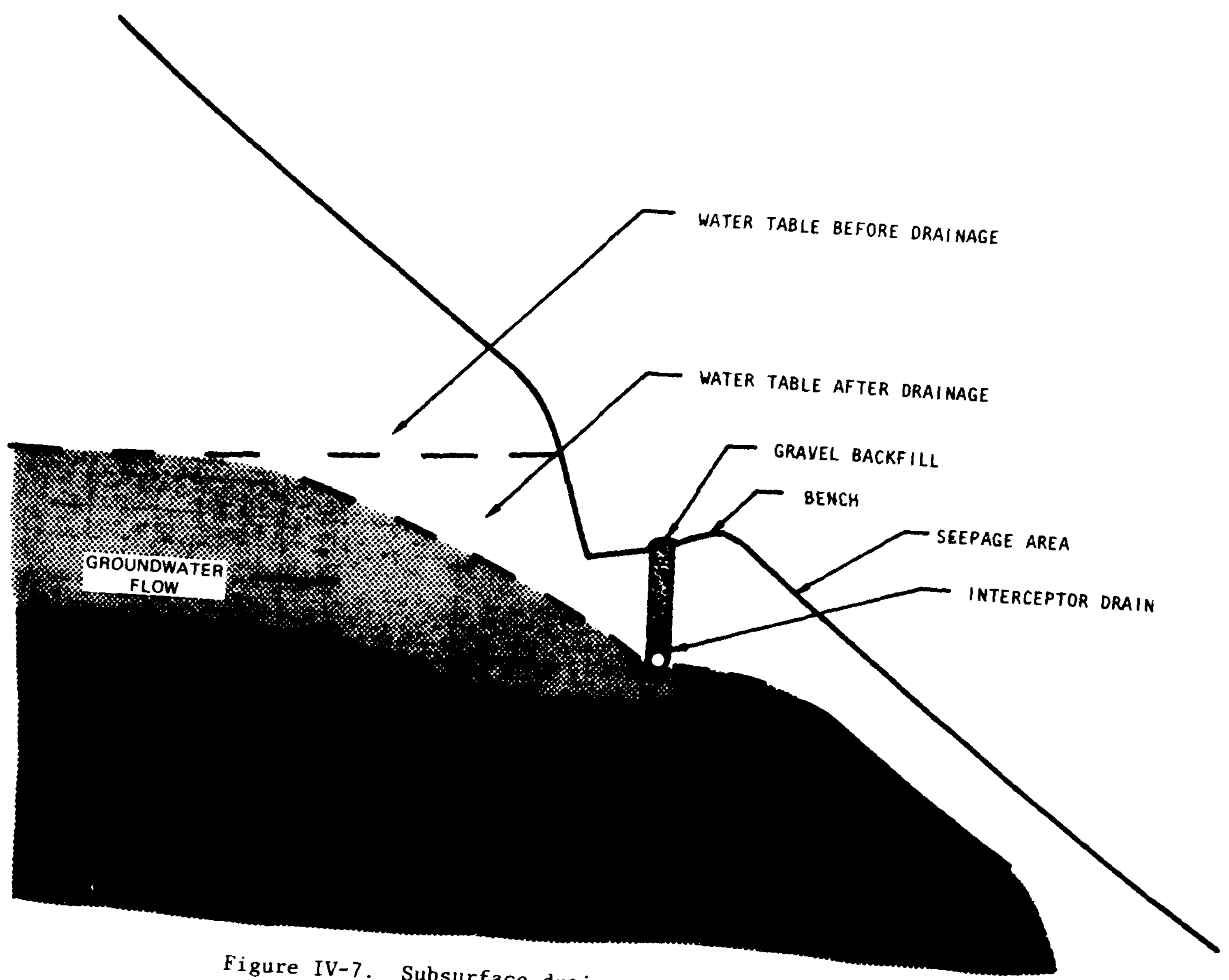


Figure IV-7. Subsurface drainage and bench on steep cut slope

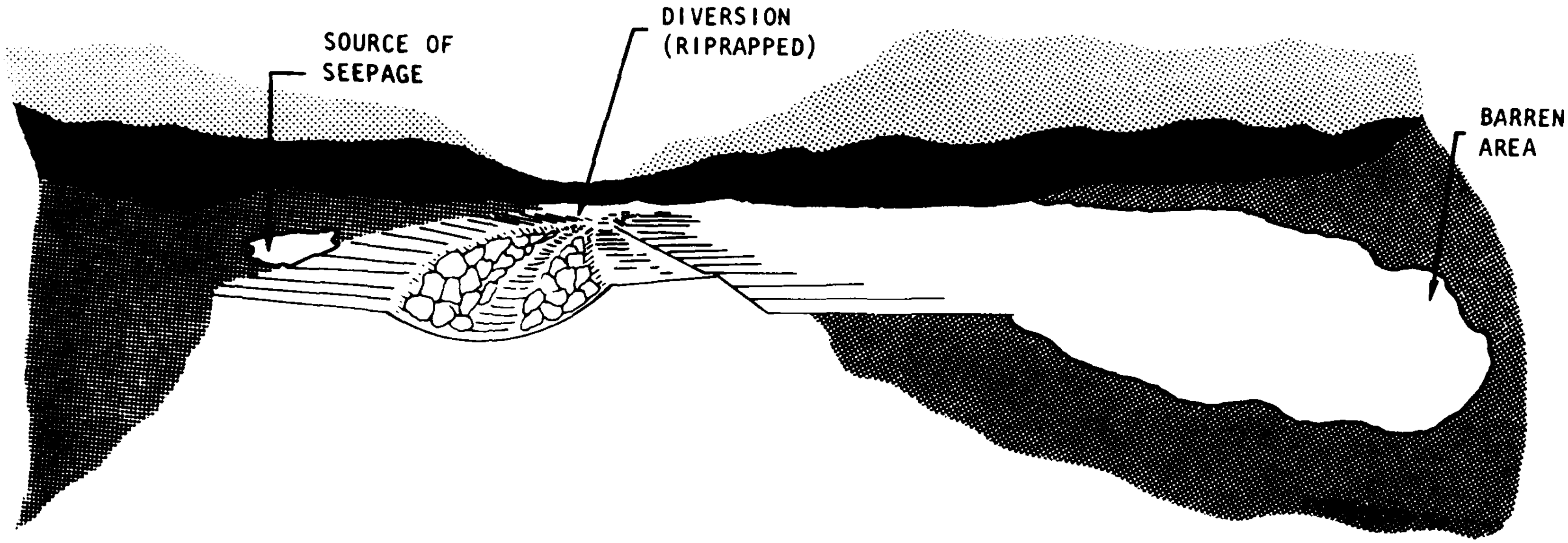


Figure IV-8. Diversion of acid flow

- Barren soil areas on level to gently sloping natural sites require diversion measures to carry the overland highly acidic flow away from the problem area. Channels should be riprapped with crushed limestone to handle the acid water. In addition, the use of limestone-filled sumps and filters has been very effective in the United Kingdom to control acid drainage (Costigan, Bradshaw, and Gemmell 1981). Proper soil conditioning, such as lime applications, is required for revegetation (see Section V).
- Barren soil areas on level to gently sloping natural sites require diversion measures to convey the overland acidic flow away from the problem area(s) (Figure IV-8). Drainage channels shall be riprapped. Critical areas often have a high water table due to the artificial tableland effect created by the fill. A subsurface drainage system is required to draw down the water table and provide a rooting zone of 12 in. for grasses and legumes and 18 in. for shallow rooted trees.

191. Nonpyritic naturally acid soils. The pH of the nonpyritic naturally acid materials can be increased easily by a single addition of limestone or other base-containing materials (e.g., carbonates, hydroxides, or oxides of calcium and magnesium) provided the proper amount is added (based on soil tests for lime requirements; see Appendix C) to displace the hydrogen and aluminum ions held on the soil colloid complex and ions present in the soil solution.

192. The color of regolith materials is generally a useful indicator of nonacid or safe strata but not of acid or unsafe strata (Despard 1974). Failure to see pyrite is no indication of its absence. Pyrite may be present in black shales in such a dispersed, fine-grained form that it is visible only under a microscope (Vogel and Curtis 1978). This form, if present in sufficient amounts, is considered more potentially reactive than visible pyrite. Thus, all fine-grained strata such as shale and claystone must be carefully examined for pyrite and related acid-forming materials during the site evaluation.

193. Characteristics of liming materials. When purchasing and applying agricultural lime to an acid soil material, the following factors should be understood (USEPA 1976):

- Common agricultural limestone or ground limestone is the most common liming material for correcting spoil acidity. Limestone may consist mainly of calcium carbonate ($CaCO_3$), or it may contain both calcium carbonate and magnesium carbonate ($MgCO_3$). Limestone that contains about as much magnesium carbonate as calcium carbonate is called dolomite. Limestone

containing lesser proportions of magnesium carbonate is called either calcitic or dolomitic limestone depending on the magnesium content. Other liming materials include quicklime, hydrated lime, chalk, marl, and fly ash. The addition of rock phosphate to acidic spoil in West Virginia surface mine areas has been reported to permit the adequate growth of grass mixtures at pH 3.5.* On those sites where basic slag is readily available in the proximity of the site, it is an excellent neutralizing material, but it usually costs more than limestone.

- The total capacity of lime to correct acidity, or the neutralizing value, is measured by the calcium carbonate equivalent.
- The size of the particles of the liming material is usually the best guide to the rate at which soil acidity can be corrected. The smaller the particles are, the faster the lime can correct acidity. The coarser the lime particles, the less reactive the material.
- The ideal time for lime application is 3 to 6 months prior to seeding. When this is not possible, the finest ground limestone should be purchased and thoroughly mixed with the soil as far in advance of seeding as possible.
- Lime should be applied immpediately after grading, regardless of season, and worked into the soil to a depth of 6 in. On extremely acidic soils, lime should be applied at least to a depth of 10 to 12 in. As the rate of limestone application is based on a 6-in. depth, rates must be doubled for 12 in. and tripled for 18 in. of incorporation.
- Lime can be applied by truck, tractor-drawn spreaders, and by hand broadcasting. On steep slopes, lime can be applied by rear-mounted blowers attached to liming trucks. In remote areas, the use of aerial techniques could be considered.
- Maintenance liming may be required for grass-legume mixtures over a 3- to 5-year period following the initial application, based on tests for lime requirements.

194. Applications of fine agricultural limestone and coarse (1/4-in. size) limestone gravel were effective in raising soil pH from 2.9 to 5.5 on exposed pyritic soil materials in northern Mississippi (Lee et al. 1983). Use of a limestone gravel was believed to reduce additional limestone applications to maintain a soil pH of approximately 5.5 for at least 10 to 15 years. These tests plots will be monitored for long-term pH changes.

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* Personal Communication, Water Armiger, Agricultural Research Center, US Department of Agriculture, Beltsville, Md.

195. Soil pH and lime requirement. When liming extremely acid (i.e., pyritic) soil materials, the amount applied must be based on appropriate tests for lime requirement and the potential acidity (PA) method of Barnhisel (1976c). As lime requirement procedures have been designed for different clay minerals, procedures employed by the local state soil testing laboratory should be used. One requirement of the buffer pH procedure being used is cited in Shoemaker, McLean, and Pratt (1961) for soils containing large quantities of adsorbed hydroxy aluminum. The buffer pH test should be adequate when the sulfide minerals are known to be low. If several tests are made, use the higher lime requirement estimate of the two procedures. Table IV-8 shows lime application rates needed to adjust mineral soils to a pH of 6.0 to 7.0, based on the SMP buffer test. On project sites, adjustment to a pH of 5.5 is adequate for plant materials adapted to strongly acid conditions (e.g., lovegrass and switchgrass).

196. The PA test for extremely acid soils (see Appendices C and H for details) is used on samples suspected of having very high sulfide levels. In this test, a 30 percent hydrogen peroxide (H_2O_2) solution oxidizes the pyritic and related sulfide minerals to give a potential total acidity (PA) value. The length of time that soil materials have already undergone weathering and leaching on the site prior to determining the PA value would determine the amount of sulfides that have yet to undergo peroxide (H_2O_2) oxidation. All buffer tests do not measure all of the acids released by the H_2O_2 treatment since they measure only titratable acidity; thus, they underestimate the amount of limestone required to increase and maintain the soil pH at or below a pH of 6.0. Additional research is ongoing at the University of Kentucky Agronomy Department and elsewhere to further evaluate these and other test relationships on pyritic materials (Barnhisel 1976a, 1976b, 1976c). (See Appendix H for details for determining total acidity and lime requirements.)

197. The lime requirement for the naturally acid nonpyritic soil materials can be determined by using the standard soil:water pH test along with the buffer pH value for agricultural soils. The pH alone cannot give an estimate of lime requirement. All lime requirement tables use both the water pH and the buffer pH to estimate lime requirements needed to raise the water pH of the soil to a definite value. If the salinity level is believed to be high, the SMP buffer pH test (or its equivalent) can be used (Shoemaker, McLean, and Pratt 1961; US Salinity Laboratory Staff 1954).

Table IV-8

Limestone Application Rates for SMP Buffer pH Tests*

Soil and Buffer pH	Indicated pH: Mineral Soils 7.0	Mineral Soils 6.5	Mineral Soils 6.0	Organic Soils 5.2
7.0	0.0	0.0	0.0	0.0
6.9	0.3	0.3	0.2	0.2
6.8	1.2	1.0	0.8	0.6
6.7	2.1	1.8	1.4	1.1
6.6	2.8	2.4	1.9	1.5
6.5	3.7	3.1	2.6	2.0
6.4	4.6	3.9	3.2	2.4
6.3	5.5	4.6	3.8	2.9
6.2	6.3	5.3	4.3	3.4
6.1	7.1	6.0	4.9	3.8
6.0	8.0	6.7	5.5	4.2
5.9	8.9	7.5	6.1	4.8
5.8	9.7	8.1	6.6	5.2
5.7	10.6	8.9	7.2	5.6
5.6	11.4	9.6	7.8	6.1
5.5	12.3	10.4	8.5	6.6
5.4	13.2	11.1	9.1	7.0
5.3	14.0	11.7	9.6	7.4
5.2	14.9	12.5	10.2	7.8
5.1	15.8	13.2	10.8	8.4
5.0	16.7	14.0	11.4	8.8
4.9	17.6	14.7	12.0	9.2
4.8	18.4	15.5	12.6	9.6

* Agricultural lime with 95 percent passing 8 mesh, 40 percent passing 100 mesh, and 90 percent $CaCO_3$ equivalent; application rates in tons per acre.

Saline-sodic soil materials

198. The following land treatments apply to saline and alkali conditions and need to be performed in conjunction with proper soil conditioning measures (see below). Economic considerations need to be carefully analyzed since the costs of the following land treatments may exceed the benefits gained and the use of adapted vegetation and minimal land treatments may be a better alternative.

- When the source of saline and alkaline conditions is due to the flow of water containing soluble salts from the more elevated locations to lower lying terrestial locations, the land will need to be shaped or graded to: (a) divert the flow of contaminant water from the area, and (b) level the uneven land surfaces where toxic materials are accumulating.
- In areas where high water tables encourage salt seepage, the water table can be lowered by: (a) ripping a clay or silica hardpan if that is determined to be the causative factor, or (b) establishing subsurface drainage systems (see Appendix D).
- The leaching of soluble salts can be accelerated through the use of an irrigation system. Sodic soil materials can be leached with solutions of neutral calcium salts (such as calcium chloride and calcium sulfate) and related chemicals at electrolyte concentrations greater than 0.5 N.

199. The selection of soil conditioning measures for strongly alkaline soils (i.e., saline, saline-alkali, and nonsaline-alkali soils for the most part) should be designed to decrease the exchangeable sodium content and decrease high salinity levels.

200. Evaluation of exchangeable sodium in alkali soils. There are several methods for evaluating the extent of the exchangeable sodium problem in highly alkaline soil materials. The calcium, magnesium, and potassium concentrations of the saturation extract of the soil can be determined by atomic absorption spectrophotometry. Sodium can be determined on the same instrument by flame emission. A nomogram can be used that relates the sodium concentration (in meq/100 g soil on Scale A) and the calcium plus magnesium concentrations of the saturation extract (in meq/100 g soil on Scale B), to estimate the sodium adsorption ratio (SAR) and the ESP on scales C and D, respectively (US Salinity Laboratory Staff 1954). Details of this rather complex scheme are reported in US Salinity Laboratory Staff (1954). Methods for collecting, handling, and subsampling soil samples are also reported as Method 1 in the same handbook. These and other methods are useful as a basis for the diagnosis, treatment, and management of alkali soils.

201. Alakli soil materials (i.e., those containing high sodium levels) limit plant growth through direct physical modification of soil structure. For example, the presence of appreciable amounts of exchangeable sodium on soil clays will disperse and puddle the soil aggregates, thereby causing poor soil aeration and low water availability to plant roots. Furthermore, if the exchange complex becomes more than 40 to 50 percent saturated with sodium, calcium can be removed from the root tissues by direct exchange with sodium ions, resulting in death of the plant because of a calcium deficiency (US Salinity Laboratory Staff 1954).

202. Evaluation of salinity. The best general method for measuring soluble salt content of soils in relation to plant growth is considered to be the electrical conductivity of the so-called saturation extract (in millimhos per centimetre). This reading is directly related to the field moisture percentage and automatically allows for the salt-dilution effect that occurs in fine-textured soils. The salinity scale for plant growth in relation to the conductivity values of saline soils (in millimhos per centimetre at 25° C) in Western areas is as follows (US Salinity Laboratory Staff 1954):

Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yield of many crops restricted	Only tolerant crops yield satisfactorily	Only a few very tolerant crops yield satisfactorily
0	2	4	8	16

Information of this type for the performance of plant materials on excavated saline soil materials is extremely limited.

203. Major limitations arise in the interpretation of conductivity data obtained by use of standard measurements of the electrical conductivity of disturbed or excavated saline soil materials containing large amounts of fine sand and coarse fragments of regolith. For example, the use of distilled water:soil ratios such as 1:1, 2:1, and even 5:1 for sands or coarser materials will often indicate a salinity hazard where none actually exists (Berg 1978). These observations suggest that more work is needed on these regolith materials in order to more accurately evaluate levels of exchangeable sodium and soluble salts at project sites in Western areas.

204. Salinity can exert direct effects on plant growth through (a) the total soil moisture stress, defined as the sum of the soil moisture tension and the osmotic pressure of the soil solution, (b) the prevention of

physiological processes that require water, and (c) the phytotoxicity due to high concentrations of boron and other toxic ions. Because of these factors, the effectiveness of a given set of remedial measures will need to be adjusted on a site-by-site basis. Review of the literature or discussion with USDA and state researchers will often eliminate the need for field and greenhouse tests. It is imperative, however, that soils from each site be thoroughly analyzed for soluble and exchangeable elements. This condition is in contrast to the alkali (sodic) soil materials which exert indirect effects on plant growth through direct effects on water infiltration rates and soil permeability to air and water (US Salinity Laboratory Staff 1954, Merrill et al. 1980).

205. Treatment should be aimed at improving undesirable soil attributes to a point at which selected plant materials can grow and reproduce over long time periods under limited maintenance. Soil conditions should also increase water infiltration and conservation (Dixon 1978, 1980). Table IV-9 summarizes materials and equipment used for the conditioning of saline-sodic soils occurring primarily in the arid and semiarid parts of the Western United States. The basic remedial measures established for the conditioning of the

Table IV-9

Materials and Equipment for Conditioning Upland Saline-Sodic Soils/Regolith

Soil Conditioning Measure	Materials Needed	Equipment Needed
Sodium removal by exchange reactions	$CaSO_4$ (gypsum) $FeSO_4$ (iron sulfate) $CaCl_2$ (calcium chloride) $MgCl_2$ (magnesium chloride) $Al_2(SO_4)_3$ (aluminum sulfate)	Applicator drill for medium to shallow placement
Leaching with irrigation water/calcium salts (gypsum)	Water low in salts $CaSO_4$ (gypsum)	Irrigators Disk plow Land levelers
Subsurface drainage	Drainage ditches Drain tile	Ditchers
Land imprinting; gouging, etc., to increase water conservation and infiltration	NA	Land imprinter Land gouger

(Figure IV-12). The speed of wind blowing at right angles to the average tree shelterbelt is reduced by 70 to 80 percent near the belt, about 20 percent at a distance 20 times the height of the belt, and only about 2 to 5 percent at a distance 30 times the height of the belt. Tree shelterbelts planted in the Great Plains in the 1930s were generally wide--consisting of 10 to 12 rows. Experience and research indicate, however, that somewhat narrower belts of medium porosity are equally effective.

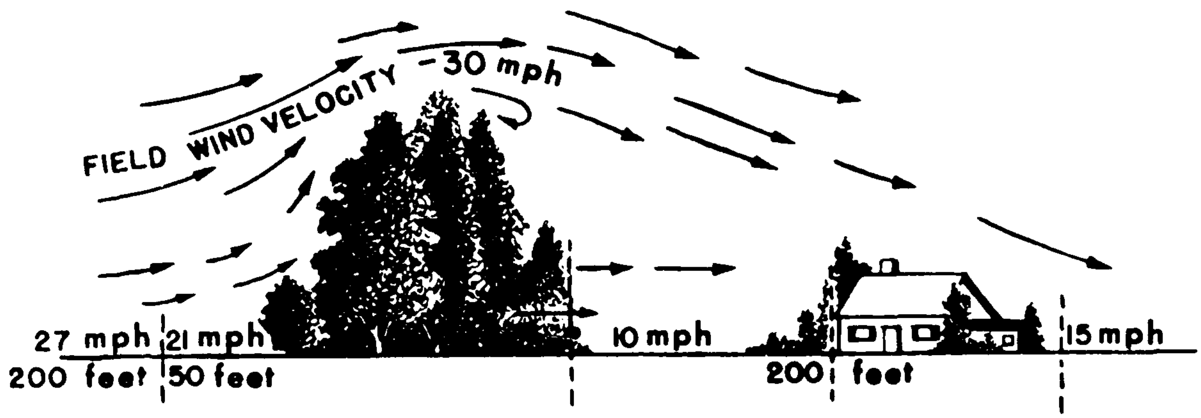


Figure IV-12. Effectiveness of a wind barrier

242. Barriers used for wind erosion control provide protection for distances ranging from 1 to 18 times their height, depending on the type used. These relatively short distances require close spacing of barriers; this reduces the fetch distance and may be objectionable on certain project sites.

243. Nearly any plant that reaches substantial height and retains its lower leaves can be used as an annual crop or grass barrier. These include pampas, tall wheat, hybrid forage sorghum, kenaf, corn, and sunflower. Spacing between annual crop or grass barrier ranges from 10 to 60 ft, depending on soil texture, control required, and other factors.

244. Artificial barriers (snow fencing, boardwalls, and earthen banks) can provide temporary protection for highly erodible areas at borrow pits, unimproved grounds, and traffic access areas. They can also be used (i.e., snow fencing) to stabilize sand dunes. They provide a relatively short zone of protection; a 4-ft snow fence protects for a distance of about 40 ft, and a 2-ft earthen bank protects for about 30 ft. These artificial barriers are costly to construct.

245. Surface roughening. The most effective roughness height for soil is 2 to 5 in. Minimum and stubble-mulch tillage leave the soil in a rougher condition than conventional tillage. Special planters, such as deep-furrow or

soil materials known to be in their natural dispersive state can be changed easily in the laboratory to a nondispersive state when mixed with small amounts of a soluble alkaline-earth compound (e.g., $CaCl_2$). When this converted nondispersive soil was analyzed by the Atterberg test, the Atterberg limits and activity readings were the same for the dispersive as for the nondispersive soils (Sherard and Decker 1976).

Wind erodible soils

238. Land treatment for soils prone to wind erosion is designed to prevent the movement of soil particles and trap and drop those particles that do become airborne. Soil conditioning measures discussed in this section (paragraphs 176-186) provide information that is applicable to some land treatment measures. The following wind erosion control measures are discussed here:

- Wind barriers.
- Surface roughening.
- Surface stabilization.
- Use of soil clods or aggregates produced by tillage.
- Soil moisture conservation.
- Techniques unique to in situ loessial material.

239. Wind barriers. Wind erosion is an avalanching process. The rate of soil flow is zero at the windward edge of an eroding site and increases to the maximum that a given wind can carry. Therefore, any measure that reduces site or slope length along the prevailing wind direction will reduce erosion. Tree shelterbelts and other wind barriers can be used to reduce site widths (i.e., fetch distance) along the prevailing wind direction. Proper layout must consider how and where to trap and drop the airborne soil particles. Soil particles that accumulate in rivers, on roadways, and next to buildings as a result of improper design, could create problems as serious as the loss of the soil itself.

240. Windbreaks and shelterbelts also reduce wind erosion by lowering windspeed, thereby decreasing soil movement. They also help retain moisture on the cropland by holding snow that might otherwise be blown into gullies and roadside ditches. Trees and shrubs (particularly native species) in one to ten parallel rows, narrow rows of field crops, snow fences, solid wooden or rock walls, and earthen banks are all useful wind barriers.

241. The effectiveness of any barrier depends on the wind velocity and direction, and on the shape, width, height, and porosity of the barrier

only the susceptibility of clay soil aggregates to dispersion and do not estimate the relative rates of clay swelling and soil erosion. Current wisdom suggests that differences in the swelling potential of 2:1 clay minerals may largely account for this anomaly. Other considerations or factors controlling clay dispersiveness include the chemical interactions between the minerals and the type and concentration of dissolved salts in the soil solution and in the eroding waters (Sherard and Decker 1976). Noncohesive silt, rock flour, and very fine sands also disperse in water, but the dispersive forces are not controlled by electrochemical properties at the surfaces of clay micelles (Sherard and Decker 1976).

235. Rainfall erosion damage on slopes having dispersive clays is not necessarily preventable by a good grass cover. This type of erosion (i.e., piping and jugging) is influenced by water entering and eroding the walls of drying cracks and crevices. The removal of soil moisture by grass roots may add to the development of surface cracks in dispersive clays (Sherard, Dunnigain, and Decker 1976). Therefore, any surface covering (i.e., mulches) that prevents rapid soil drying and shrinking can protect against this problem.

236. Unusual erosional patterns in the field such as piping, jugging, tunneling, and gullying help to identify the presence of dispersive clay soils. The absence of any unusual erosional patterns, however, does not mean that the soils are not dispersive. Soil survey maps provided by the USDA/SCS provide valuable data in evaluating the potential hazards from dispersive soils. Present consensus is that the four basic laboratory tests in current use by the Soil Conservation Service should be applied to each soil specimen as follows:

- The SCS pinhole test--this appears to be the best test to date; it models the erosional performance of clay soil materials when they are subjected to the erosive action of a concentrated stream of water.
- Test of dissolved salts in the pore water.
- The SCS dispersion test on soil samples at their natural moisture content (undried); distilled water is used for dispersion testing.
- The soil aggregate (i.e., crumb) test.

237. These tests should be made on a large number of samples. Atterberg limits, particle-size distribution, and visual classification schemes have proved to be inadequate. It has been shown that typical high-sodium clay

Table IV-12

Materials and Equipment for Conditioning Dispersive Soils/Regolith

Conditioning Measure	Materials Needed	Equipment Needed
Burn, excavate, and batch mix soils and lime	Hydrated lime [$Ca(OH)_2$] Slaked lime (CaO) plus water	Grader/loader
Treat soil compaction	$CaSO_4$	Ripper, subsoiler, scarifier
Use a sand-gravel blanket or other nondispersive soil blanket	Sand/gravel	Trucks
Selectively incorporate organic matter	Composted sludge/ composted sawdust	Ripper or subsoiler and turnplow

Table IV-13

Comparison of Some Construction Practices Used for Treatment of Dispersive Soils*

Method	Advantages	Disadvantages
Hydrated lime treatment	Provides stable embankment shell	High cost, difficult to establish vegetation
Sand-gravel blanket	Provides friable, flexible blanket; prevents drying and cracks	Rills develop on slopes; requires maintenance; fines may have to be added to aid vegetative growth
Topsoil, full scraper width on outside shell	Good material for establishing vegetation; more erosion resistant than underlying material	May not be available on site; may require maintenance
Topsoil, thin blanket outside shell	Good material for establishing vegetation	May not be available on site; maintenance definitely required

* Sherard and Decker (1976).

Dispersive clays and
related geotechnical materials

231. For certain dispersive clay areas, it is essential to divert the flow of water before the area can be restored. This is accomplished by grading and shaping the soil surface and using control structures. The water flow will need to be diverted without decreasing the water quality of the watershed. It is important that proper soil conditioning treatments for dispersive clays are applied to avoid failure of a graded area or structure. Excavation and burial of dispersive materials and selective placement of nondispersive soils in critical areas that may be subject to concentrated flows should be considered (see paragraphs 162-175).

232. Dams have been built with impervious cores of dispersive clays. Sand filters are usually used at these sites to provide adequate drainage and prevent erosion damage to the core from internal piping. There have been no reported problems except where no sand filter was used. Opinions on the suitability of using dispersive clays for dam cores differ. Additional information on this subject can be found in Sherard and Decker (1976). The side slopes of canals have sometimes shown signs of cracking, sliding, and sloughing in areas where dispersive clays exist. Stability can be restored by removing portions of the canal lining, flattening the slopes, and relining the canal using a compacted soil-lime mixture. More details can be found in Howard and Bara (1976).

233. Soil conditioning measures for dispersive clays should be designed to (a) decrease the exchangeable sodium content of 2:1 clay minerals, (b) decrease the high pH values of the piped and jugged soil materials, and (c) decrease the rate at which the dispersive clays shrink and swell. Table IV-12 summarizes the materials and equipment used for conditioning dispersive soils. The advantages and disadvantages of methods for treatment of dispersive soils are shown in Table IV-13.

234. If the soil/regolith materials at project sites exhibit deep gullies, piping, and/or jugging, they are probably in the dispersive state. Research data reveal, however, that clays found naturally on excavated slopes and embankments may resist erosion damages from rainfall, even though the laboratory test data revealed them to be in a dispersive state. This makes it difficult to predict whether or not a given dispersive soil will be badly eroded or dispersed by concentrated water flows. Laboratory tests measure

radically affect the water and air conditions within the soil profile. For example, soil materials in low-lying, poorly drained areas will not only collect more surface water than soils located in high spots, but the former soils will exhibit markedly different properties than those in the better drained areas.

228. The overly compacted soil layers in excavated material disposal sites are often created between layers of distinctly different types of soil materials laid down randomly. Generally, the clay loams, very fine sand, and silty clays (and combinations thereof) exhibit the greatest potential for compaction by heavy machinery during construction work.

229. The primary objective of the evaluation of poorly drained upland soil materials is to ascertain their drainage requirements, with specific reference to:

- Depth, type, and mode of variation of the water table(s) with respect to the soil surface and the quantity of water that a drainage system must transport (both surface and subsurface waters).
- Water-transmission properties of the soil materials (horizontally and vertically).
- Texture, position, and extent of subsurface soil materials (stratigraphy).
- Soil structure.
- Particle-size distribution--soil materials having a continuous range of particle sizes are less permeable than those having essentially a uniform range of particle sizes (US Salinity Laboratory Staff 1954).

230. Evaluation of the physical and chemical properties of poorly drained soils. Important attributes of poorly drained soil materials that may require close study include texture, bulk density, degree of soil compaction, soil structure, soil porosity, hydraulic head of ground water, and water-transmitting properties. Details on the evaluation of these properties can be found in Appendix C. Additional information in evaluating soil drainage includes determination of (a) water-transmitting rates, (b) hydraulic conductivity (related to soil texture and structure), and (c) subsurface stratigraphy. While the most common indicator of drainage adequacy is depth to the water table, other common indicators are hydrophytic plants (cattails and sedges) and the presence of ponded water.

223. The selection of measures for improving internal soil drainage should be designed to accomplish one or more of the following actions:

- Increase soil aeration by draining excess water from waterlogged soil pores.
- Increase surface soil temperatures.
- Ameliorate the compacted soil layers, including developing or incipient claypans and hardpans.
- Remove perched and/or high water tables.
- Select plant materials that are tolerant of waterlogged and poorly aerated soils, provided that they are compatible with land management goals.

These and other soil conditioning measurements must be consistent with land management and land use objectives already adopted for specific CWP/DOA sites.

224. Evaluation of internal and subsurface drainage of poorly drained upland soils. The most common field indicator of imperfect internal and subsurface drainage is the presence of mottling at various soil depths, dominance of hydrophytic vegetation, and indications of free-standing water. A thorough investigation of soil drainage problems requires detailed information at the site on the following factors:

- Depth to ground-water table (including perched water tables).
- Properties of soil materials (hydraulics, permeability, compacted layers).
- Topography.
- Soil structure.

225. Considerable savings can be realized, however, if plant materials that are adapted to waterlogged upland soils can be used, provided that this approach is compatible with the land management objectives already established for the site(s).

226. From the standpoint of internal soil drainage problems (horizontal as well as vertical), the properties of the soil materials below the water table are of greater importance than the soil materials near the surface. The latter soil materials may exhibit entirely different water-transmitted properties than those of similar texture located below the water table (US Salinity Laboratory Staff 1954).

227. Waterlogged soil materials can be expected to occur on subhumid and humid region project sites where the subsurface strata have been overly compacted by heavy-gauge earthmoving equipment. An important complicating factor is the physical relief of the project site. Local relief will

- In areas where the poor internal drainage conditions result in seepage areas, use the same corrective methods outlined for highly acidic conditions. If the seep is not toxic, the treatment method would require less riprap and catchment basins would not be required.
- If a high seasonal water table is the problem (particularly due to snowmelt or heavy rains), these areas should be avoided when wet. They can be easily vegetated with perennial species, if there are no other limitations to plant growth from other hostile interactions at the site. A riprapped channel may be required if the flow leaving the critical area causes problems.
- If clay lenses and other impeded strata have been identified during the site survey as the cause of the poor internal drainage conditions, then ripping of this layer to allow infiltration of water to lower soil layers may be helpful.

222. The poorly drained upland soil condition may be found in surface accumulation (or ponding) of surface runoff and in slow internal and subsurface drainage rates in the vertical soil profile. The land-shaping measures discussed above are appropriate for eliminating surface runoff accumulations. Soil conditioning measures for the resolution of imperfect internal drainage are given in Table IV-11.

Table IV-11

Materials and Equipment for Conditioning Poorly Drained Upland Soils/Regolith

Soil Conditioning Measure	Materials Needed	Equipment Needed
Land shaping and smoothing	(See Section IV)	Graders/dozers
Deep ripping to remove compact layers	NA	Ripper, equipped with multilevel chisels
Subsurface drainage system	Drain tile	Trenchers Ditchers
Addition of organic materials		
Addition of coarse-grained material		

air dried and carried through a sieve analysis or other standard methods for measuring the silt and clay fraction. Coarse-grained materials require only grain-size analyses. Data from the particle-size distribution analyses can be used to classify the soil materials according to the Unified Soil Classification System (US Army Engineer Waterways Experiment Station 1960) or the USDA scheme (USDA, Soil Survey Staff 1951). Chemical analyses of the soils may be made according to procedures listed in Appendix C.

Poorly drained soil materials

219. Soils with poor surface drainage are not covered here. These areas are small compared to internal drainage problems. Localized depressions can be filled and the surrounding area leveled so that water does not collect. Water control measures are needed to handle the surface flows. Plant species adapted to these adverse conditions can also be used and no land treatment measures need be undertaken.

220. For soil with poor internal drainage, either no land treatment or land treatment to improve the conditions enough to support the establishment of vegetation should be considered. Not all waterlogged sites are inherently poorly drained, but they could become so if influenced by other conditions. The degree of traffic and slope and the use of the soil dictate the practices necessary to reclaim these critical areas. Cut slopes are most dangerous in waterlogged conditions due to the slide potential.

221. Specific treatments that may apply to a particular problem soil area include the following:

- If the site in question is located so that it does not pose any danger to nearby resources (highways, adjacent property, etc.) should it slide due to the waterlogged conditions, then the option of doing nothing should be considered. This is the least costly approach. The site could be enhanced simply by planting water-tolerant shrubs, trees, and other permanent vegetation.

- Sites in areas of high visibility and traffic (recreation areas, etc.) may need installation of an extensive internal drainage network to ensure stability of the site and allow revegetation with the desired plant species. In this instance, an interceptor tile line shall first be installed to cut off outside sources of internal flow and a diversion created to cut off surface flows of water to the site. (A proper outfall for the intercepted water should be looked for in the evaluation of the site.) The high water problem needs to be reevaluated after these structures have been installed to determine the necessity of installing an internal drainage network throughout the site.

214. Evaluation of the depth and vertical thickness of excessively drained soil materials. Hand augers, power augers, power-driven core-sampling tubes, standard well-drilling equipment, and jetted piezometers can be used for characterizing the depth and vertical thickness of subsurface layers. Among these, the driven tube (to get an undisturbed soil core) and the jetted piezometer are best to characterize this problem soil.

215. Undisturbed cores, 4 in. in diameter and from depths up to 10 ft, can be obtained by using the power-driven core-sampling machine, an earlier model of which has been described by Kelley, Hardman, and Jennings (1948). This machine is trailer mounted and is usable over terrain passable to trucks. Soil cores are useful for the observation of structure and for making various physical measurements on undisturbed subsoil materials. Cracks, root holes, and fine sand lenticles may be overlooked with augering and other sampling methods, but are preserved for examination in an undisturbed core (US Salinity Laboratory Staff 1954).

216. The development of the jetting method of installing piezometers has made subsoil investigations possible at a fraction of the cost of augering or other well-drilling methods. Piezometers may be jetted for the sole purpose of determining subsoil stratigraphy, or the pipe may be left in place after the soil log is obtained as a permanent installation for hydraulic-head measurements.

217. Subsoil logs from jetted piezometers are usually made on the basis of texture (particle size) because it provides an indication of the water-transmission properties of soils. Depths of strata changes may sometimes be obtained to within ±0.1 ft by this method, and soil layers can be distinguished that are too thin to be logged by well-drilling methods. An estimate of the texture and consolidation of the material is made from (a) the vibration or feel of the pipe to the hands during the downward motion, (b) the rate of downward progress, (c) examination of sediments carried by the effluent, and (d) observation of color changes that occur in the effluent (US Salinity Laboratory Staff 1954).

218. Evaluation of the physical and chemical composition of excessively drained soils. Soils may be analyzed in the field by visual and tactile valuations. It is easy to establish whether the soil materials are predominantly coarse grained and essentially devoid of silt and clay particles. Samples that appear to be a mixture of both coarse- and fine-grained particles must be

- Excessively drained soils are prone to wind erosion if the soil particle size is fine enough. Wind erosion control practices may need to be incorporated at a particular site.

212. Excessive drainage can occur in the form of very rapid surface runoff and also as very rapid internal or subsurface drainage of the soil profile. Rapid surface runoff occurs wherever slope lengths exceed 40 ft and the slope angles exceed about 30 percent. Slope modification measures for resolving excessive surface drainage have already been discussed above.

213. Soil conditioning measures for soil materials having excessive internal drainage should increase their moisture- and nutrient-holding capacity and decrease their potential for erosion by wind action (i.e., saltation and surface creep). Further successful conditioning should decrease the soil's permeability to water, increase the cation-exchange capacity, and decrease surface soil temperatures. Soil conditioning measures that will increase the moisture- and nutrient-holding capacity should be put into place well ahead of the customary seedbed preparation. Conditioning to achieve the other requirements is best handled during seedbed preparation. Considerable savings can also be realized by using plant materials that have (a) low nutrient requirements (i.e., for nitrogen, phosphorus, calcium, etc.), (b) high resistance to drought and excessive soil temperatures, and (c) the capability of sending down a deep and widely spreading root system (see Section V). Table IV-10 summarizes materials and equipment that contribute to the conditioning of excessively drained soils.

Table IV-10

Materials and Equipment for Conditioning Excessively Drained Upland Soils/Regolith

Soil Conditioning Measure	Materials Needed	Equipment Needed
Incorporation of soils having 25% silt and clay	Subsoils and regolith meeting Corps specifications	Ripper, turnplow
Incorporation of composted sludge, digested sludge, animal manures, sawdust, and other organic materials	Composed sludge, digested sludge, animal manures, and sawdust	Ripper equipped with multidepth applicators, turnplow

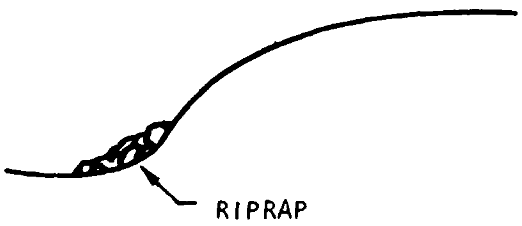


Figure IV-10. Fill out excessively drained sands

- Fill or disposal site areas consisting of excessively drained, highly erodible soils require a peripheral storm water carrying structure to divert water from the fill. If a cap of heavier soils (S + C = 20%) is placed on the disposal area, it should be rounded along the outside perimeter so moisture holding for revegetation is not a problem at that edge (as it would be with a sharp angle).
- Land treatments for excessively drained shales are handled in a fashion similar to that of sands. As it weathers, shale exhibits a shingling effect and rapidly sheds water on slopes. Shale carried by water cuts off plants; therefore, serrated cuts are needed on slopes to catch this material as it breaks down. This builds up soil on the level areas of these cuts.
- Gravelly soils should be mixed with fine-textured soils if they are in sufficient quantity to make it economically feasible. Otherwise, they should be treated the same as excessively drained sandy soils.
- Stones (fragmented materials) should be used as rock riprap on other areas of the site that require such materials due to toxic seepages, concentrated water flows, etc. This is a cost-saving procedure that can easily be implemented whenever feasible.
- Cuts through excessively drained stoney soils should be left alone if they are stable. Serrated cuts or benches should be incorporated in unstable cuts or on long, steep slopes.
- Stoney soils can be used in the lower lift of excavated material disposal areas as a filter material (see Figure IV-11).

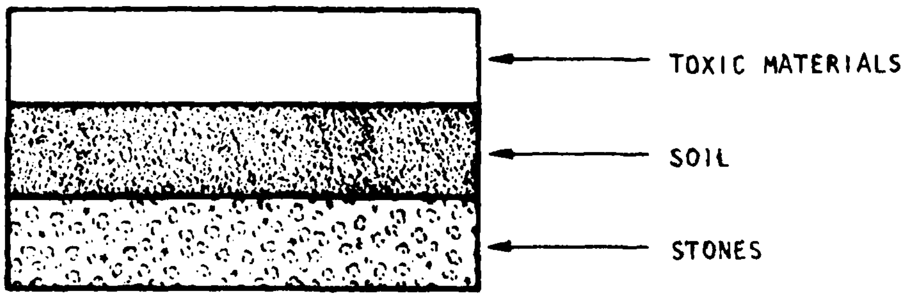


Figure IV-11. Stoney soils as filter material

the Western United States are presented elsewhere (US Salinity Laboratory Staff 1954, USDA, Forest Service 1979c).

Excessively drained soil materials

210. Excessive surface drainage for shallow, dry, gravelly/rocky slopes can be treated by shortening slope lengths, using water control measures such as diversions, incorporating waterspreading techniques, and by using water harvesting methods (in arid/semiarid areas). The alternative of taking no action and using adapted plant materials is also a possibility.

211. Land treatment of soils with excessive internal drainage varies with the type of material: sand, shale, gravel, or stone. Remedial measures must include the addition of organic matter as part of the soil conditioning measures if vegetation is to be established (Coppin and Bradshaw 1982). Land treatments that may apply to a particular site problem include the following:

- Cuts through excessively drained sands will stabilize at a vertical angle but are impossible to vegetate. This angle has to be seen to collect moisture for sustaining vegetation through droughty periods, etc. A header ditch is needed at the top of the cut so that gulleys do not occur (Figure IV-9). No provision for drainage of the collected flow is needed unless other problems such as high acidity are present.

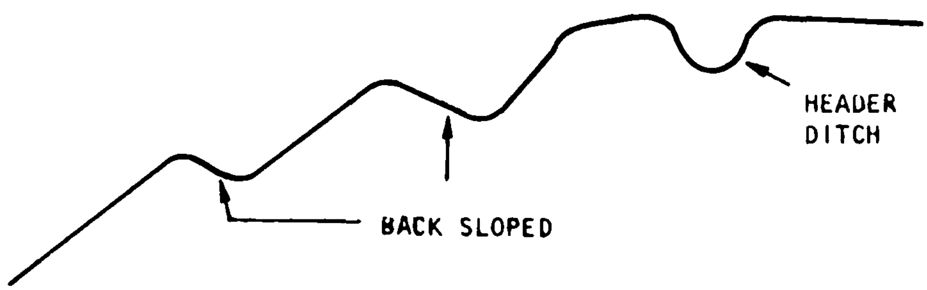


Figure IV-9. Cut through excessively drained sands

- Fills of excessively drained sandy materials that are in an area of public use (i.e., not a disposal site) may require the use of riprap reinforcement at the base of the slope for stabilization (Figure IV-10).

saline-sodic soils of the Western United States have been strongly influenced by the need for the producers of vegetable, fruit, and staple crops to maintain these soils in a condition that will maintain the highest crop yields. These stringent and rather costly measures will, as a general rule, not be required for the advance conditioning of soil materials on most project sites for reasons cited earlier in Section IV.

206. For purpose of this discussion, it is assumed that (a) strongly alkaline problem soils at most project sites in the Western United States will not exceed 30 percent of the total site area, (b) they may range in age from <1 to 60 years or more, and (c) previous attempts to revegetate were unsuccessful. The following reasons are given for unsuccessful revegetation:

- The plantings were unprotected from the inroads of fire and/or grazing animals.
- Salt- and alkaline-tolerant plant species were not used.
- The best planting method and/or planting date were not used.

207. Three classes of alkali soil materials (i.e., those having high exchangeable sodium levels) are noted, as follows (US Salinity Laboratory Staff 1954):

- Those containing alkaline-earth carbonates.
- Those containing no alakline-earth carbonates and a pH of 7.5 or higher.
- Those containing no alkaline-earth carbonates and a pH of less than 7.5.

208. The improvement of alkali soils requires use of gypsum, sulfur, calcium polysulfide (lime-sulfur), iron sulfate, ammonium sulfate, and other soil amendments which react chemically by removing exchangeable sodium from the soil colloidal (cation exchange) complex. The chemical amendments sulfur and lime-sulfur, and iron sulfate act to acidify the soil. When the amount of these acid-forming amendments needed for reclamation makes the soil excessively acid (i.e., less than pH 5.5), limestone must be used to raise the pH to levels that (in arid regions with 2:1 type clay minerals) are most beneficial to plant growth (pH 6.0 to 6.5). Gypsum is widely used to avoid the excessive acidification problem during the reclamation of alkali soils.

209. The improvement of saline soils requires the use of irrigation, leaching, and the removal of excess water from the soil by surface and subsurface drainage. Collectively, these terms comprise the essence of water management in arid and semiarid regions. Basic principles of water management in

hoe drills, with a roughness in the 2- to 5-in. range, are especially effective in providing wind-resistant surfaces. Emergency tillage, in which land is roughened with chisels or listers, is used as a last resort when vegetative cover is not adequate to provide control (USEPA 1973a).

246. Surface stabilization. The use of nonvegetative stabilization practices should also be considered for certain critical sites. Further details can be found in Section VI.

247. Use of soil clods or aggregates produced by tillage. Soil clods or aggregates larger than 0.84 mm in diameter are not moved by winds under 30 mph. The degree of cloddiness needed to control wind erosion depends on other factors that affect wind erosion. The size of clods required under various circumstances can be calculated with the wind erosion equation. The degree of cloddiness produced by tillage depends on such factors as soil textures, soil moisture, speed of operation, and kind of tillage tool. Generally, the maximal cloddiness is achieved by using 2-in. chisels and 32-in. sweeps, followed in order by disks, rod weeders with shovels, and large V-sweeps (USEPA 1973a).

248. Soil moisture conservation. Distribution of available moisture on surface soil materials that are prone to wind erosion helps reduce their erodibility. If the soil is moist, the adhesion between particles is much greater and, therefore, erosion due to wind is substantially reduced. The extra moisture also aids in the establishment and maintenance of vegetation. While irrigation is in most cases an economically infeasible alternative for wind erosion control unless it is already in use for vegetative establishment, the incorporation of waterspreading techniques into the site restoration plan should be considered.

249. Land is sometimes leveled or benched for purposes of water spreading, water erosion control, and moisture conservation. These land modifications affect the rate and amount of wind erosion. Research information on the relationship between land modification and wind erosion is meager. Estimates for average Great Plains soil conditions indicate that shortening of fetch distance from 1000 to 100 ft by benching reduced potential soil loss by wind by 50 percent. Another calculation concerning a 1200-ft-long, 4 percent slope, benched with a series of 240-ft-wide level benches, showed that soil loss from wind erosion was reduced 60 percent. Additional field trails are needed to establish the value of this and other measures on project sites.

250. Soil conditioning measures for wind erodible soils should be designed to (a) prevent the spread of existing dune areas to more productive land areas, (b) control grazing and traffic on lands susceptible to wind erosion, (c) reduce slope lengths and site widths facing the direction of prevailing winds, (d) increase soil moisture levels through use of water harvesting and waterspreading techniques (e.g., benching/leveling), and (e) decrease wind speeds and fetch distances. Slope manipulation and increased moisture levels must be carried out in advance of vegetative establishment and were discussed earlier in this section. Control of grazing and traffic is an administrative matter that can be handled by fencing and other restrictions on lands known to be susceptible to wind erosion. Table IV-14 summarizes the soil conditioning measures that have value or promise for managing wind erodible soils.

251. Wind erosion is accelerated on bare slopes facing the dominant wind direction because the wind impinges against the slope. On long slopes (i.e., long fetch distances) facing the dominant wind direction, accelerated wind erosion can be a much greater problem than on short slopes. Other major factors affecting the amount of wind erosion from exposed soil surfaces are as follows (National Research Council, Transportation Research Board 1980):

- The susceptibility of the soils to wind erosion.
- The wind velocity and annual precipitation effectiveness index.
- Prevailing wind direction and prevalence.
- Soil roughness (natural or artificial).
- The soil organic material preponderance relative to the mineral portion.
- The unshielded wind fetch distances.

252. The following simple field test may be applied to determine the susceptibility of various soil materials to wind erosion. Collect 5 to 10 samples of about 2 lb of field-weight soil from an open, exposed site. Allow the spread-out samples to dry overnight in a large oven set at about 212° F, and then sift the dry sample through a 20-mesh sieve. If more than 0.5 lb of dried soil passes through the sieve, the soil materials are susceptible to wind erosion.

253. Techniques unique to loessial material. Construction through loessial soils involves problems with the stability of in situ slopes, erosion

Table IV-14

Materials and Equipment for Conditioning Wind Erodible Soils/Regolith

Conditioning Measure	Materials Needed	Equipment Needed	Remarks
Construct shelter-belts, windbreaks, and barriers to wind	Trees (adaptable conifers and deciduous trees)	Tree planters	
		Disk plow	
	Tall shrubs (evergreen and deciduous)	Fence installers	
	Snow fence		
Create standing stubble by use of annual crops	Annual warm season grain crops/small grains, etc.	Disk plow	
		Seed drill	
Construct fences and other barriers for traffic control	Steel wire	Fence installers	
	Woven wire		
Roughen the surface		Deep furrow, hoe drills	Interim seedbed treatment measures
Produce clods/aggreates		Chisels, sweeps	Temporary in nature and usually followed by barrier plantings

of slopes, liquefaction of reworked loess, and other concomitant areas of concern (National Academy of Sciences, Highway Research Board 1968). Experience with design, construction, and maintenance of highway projects and Civil Works projects for irrigation, etc., has provided some documentation on loess soil characteristics.

254. The following design considerations with loess must be considered:

- Excavation of cut slopes leaves a cut face which has a natural tendency to slough and leave a more or less vertical face no matter at what angle the slope was cut.
- Surface drainage over a cut slope in loessial material must be controlled at all times to prevent erosion even after revegetation.
- Cracks and rodent holes pose a maintenance problem since they tend to collect water, and piping wells can develop.
- Loess soil is quite stable when given a proper degree of compaction.
- Differential settlement of areas where structures are built on loess can be a problem.

The National Academy of Sciences, Highway Research Board (1968), provides more details on these considerations. More work needs to be done in the development of more definitive policies regarding the location, design, and construction of all project sites that traverse the loess belt. Under these circumstances, development and implementation of cost-effective measures that will control wind erosion are needed (National Research Council, Transportation Research Board 1980).

SECTION V: VEGETATIVE STABILIZATION OF PROBLEM SOILS

SECTION V: VEGETATIVE STABILIZATION

SECTION V: VEGETATIVE STABILIZATION OF PROBLEM SOILS

Selection of Adapted Plant Materials

255. The purpose of this section is to discuss general and specific considerations with respect to the use of plant materials that are best adapted to the plant growth regions in which the problem soil may occur on specific project sites. The complex array of climate, topography, and soils within a given plant growth region is judged sufficiently uniform to permit the natural development of typical ecological associations of grasslands, shrublands, and forests. In 1978, R. G. Bailey, in cooperation with the US Fish and Wildlife Service, synthesized a number of concepts and systematically divided the country into ecosystem regions (Bailey 1978). These regions are similar to the plant growth regions used herein. The reader is advised that the range of naturally occurring plant species, or the area of adaptation of plant species and their cultivars alluded to in this manual, does not necessarily stop abruptly at the borders of a plant growth region. Local agency representatives who are experienced and knowledgeable in uses of native vegetative plant species should be contacted.

256. The plant growth regions used in this manual are delineated in Figure V-1 for the arid and semiarid climates of the Western United States (Thornburg 1979). In Figure V-2 plant growth regions are delineated for the subhumid and humid climates east of approximately the 100th meridian.

257. Plant materials selected for the vegetative stabilization of problem soils must initially accomplish the first two of the following four goals:

- Stabilize the soil against erosion by water, wind, and gravity.
- Minimize sediment and surface runoff and downstream impacts from contaminants.
- Improve fish and wildlife habitat and create self-sustaining ecosystems of low maintenance.
- Enhance the natural beauty (aesthetics) of the site and develop basic recreational and related resources at the site.

258. All four of these goals must be closely linked to the long-term land management objectives established for specific project sites. They must also be compatible with each other and understood by the interdisciplinary

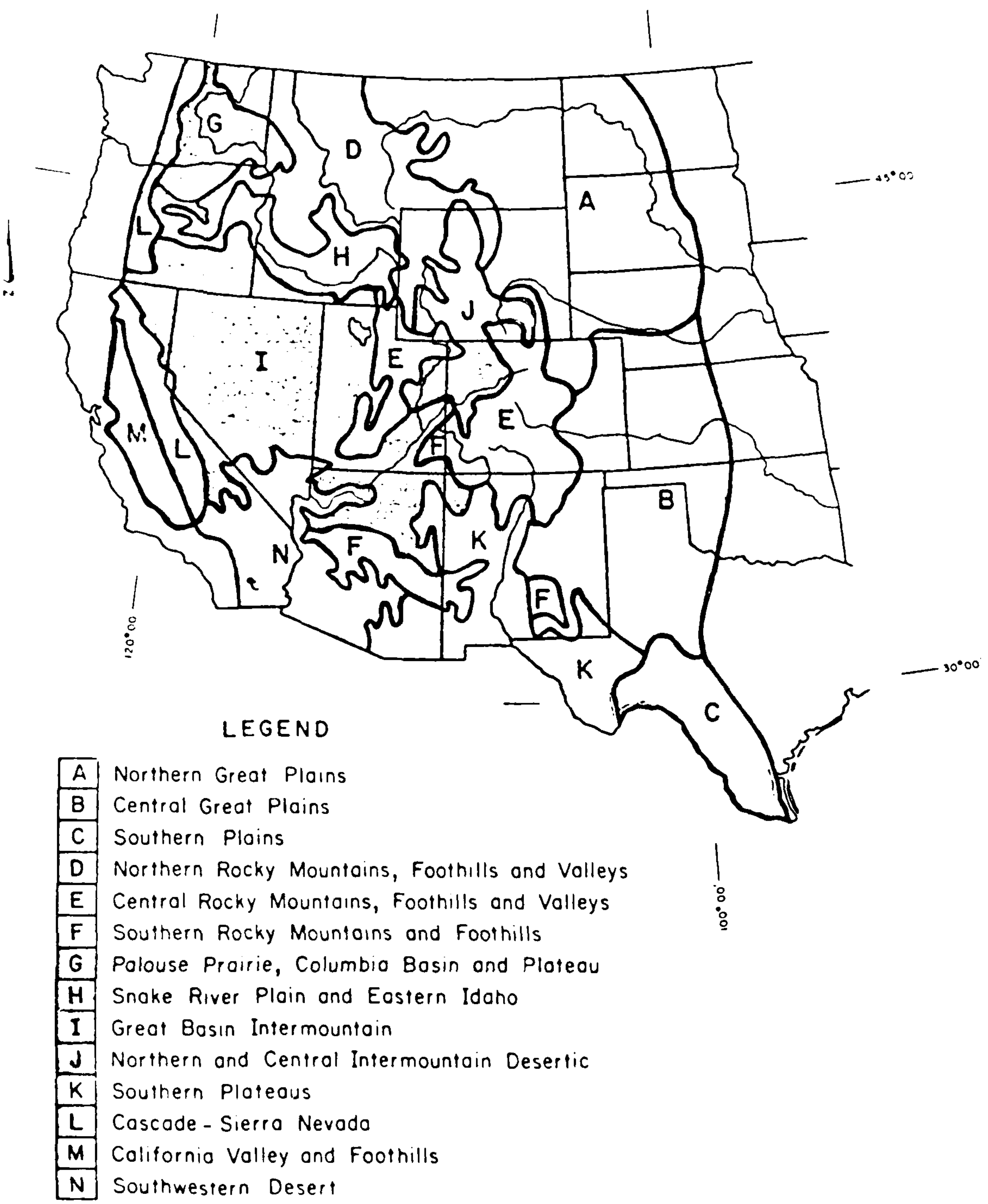
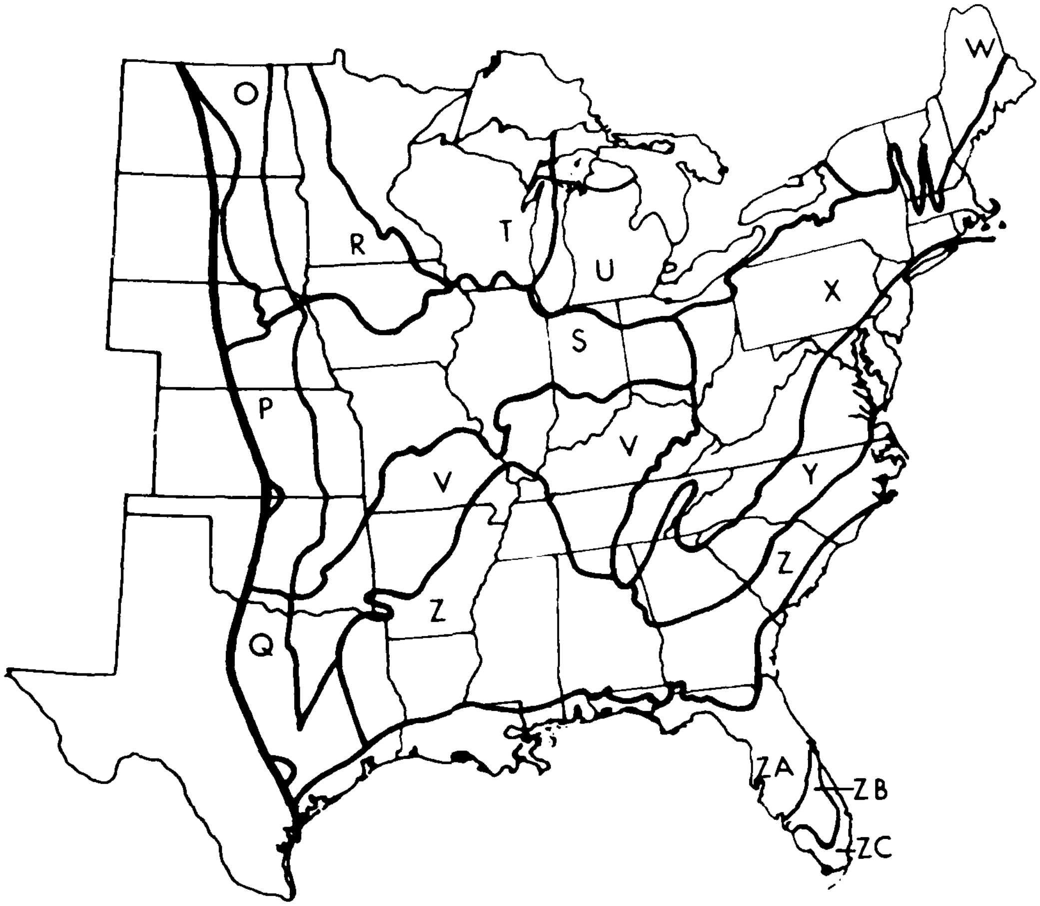


Figure V-1. Plant growth regions of the arid and semiarid areas of the Western United States (Thornburg 1979)



O NORTHERN BLACK SOILS
P CENTRAL BLACK SOILS
Q SOUTHERN BLACK SOILS
R NORTHERN PRAIRIES
S CENTRAL PRAIRIES
T WESTERN GREAT LAKES
U CENTRAL GREAT LAKES
V OZARK-OHIO-TENNESSEE RIVER VALLEYS
W NORTHERN GREAT LAKES-ST. LAWRENCE
X APPALACHIAN
Y PIEDMONT
Z UPPER COASTAL PLAIN
ZA SWAMPY COASTAL PLAIN
ZB SOUTH-CENTRAL FLORIDA
ZC SUBTROPICAL FLORIDA

Figure V-2. Plant growth regions of the United States for the humid and subhumid climates (USDA 1972)

team because they are crucial to the development of the site improvement plan, as reported in Section III.

General considerations

259. The several general issues and considerations that are highly relevant to the use of plant materials for the stabilization of project sites are:

- Criteria for selecting grasses and forbs.
- Criteria for selecting shrubs and trees.
- Breeding and selecting plants for tolerance to stress.
- Source of seeds. Use of single species versus mixtures.
- Use of adapted native species versus introduced species.
- Use of adapted ecotypes and cultivars. Undesirable species.
- Undesirable species.
- Other selection factors.

260. Appendix E contains lists of plant materials and seed mixtures that clearly have value and/or promise for use on various critical areas (i.e., problem soil environments) in arid, semiarid, subhumid, and humid climates of the coterminous United States (Clements 1920; USDA, Forest Service 1937; VanDersal 1939; Graham 1941; Martin, Zim, and Nelson 1951; Benson and Darrow 1954; Mueller-Dombois and Ellenberg 1974; Hafenrichter et al. 1979).

261. Criteria for selecting grasses and forbs (USEPA 1976). In selecting grasses and forbs (i.e., herbaceous nonlegumes and legumes) for the control of soil erosion and overland flows of water (surface runoff), the following criteria should be considered:

- Their availability in needed quantity and in the appropriate season.
- Their ability to withstand the erosive and traffic stresses present at the site being stabilized (Haynesworth, no date).
- Their adaptability to critical area soil conditions (pH, texture, drainage, salinity, sodicity, and wind erosion).
- Their adaptability to climatic condition (sunlight exposure, temperature, wind exposure, and rainfall) found at the site.
- Their resistance to insect damage, diseases, and other pests.
- Their compatibility with the principles of secondary succession, and of land management objectives (Mueller-Dombois and Ellenberg 1974).
- Their compatibility with other plants selected for use on the same area.

- Their ability to propagate (either by seed or vegetatively) themselves.
- Their short- and long-term maintenance requirements and costs.

262. To minimize the possibility of failure in establishing an erosion control cover and at the same time reduce postestablishment maintenance requirements, one must select grasses and legumes that are adaptable to the problem soil conditions found at the site.

263. Criteria for selecting shrubs and trees. In selecting shrubs and trees for habitat enhancement, and for wildlife and recreational uses of the site, the following criteria should be considered (McKell 1975):

- Their availability in required quantity and appropriate time frame.
- Their availability to produce extensive root systems in both the vertical and lateral directions, in order to exploit the maximum soil volume for nutrients and moisture (particularly true for arid and subhumid regions). In wet soils, an extensive lateral spreading of roots is an important selection trait, in preference to a strong tap root system.
- Their ability to become quickly established.
- Their tolerance of acid, saline, sodic, wet, droughty (sands), compacted (clayey), and related problem soil environments.
- Their compatibility with the principles of secondary succession.
- Their ability for vigorous growth after relief of moisture stress, and coppice formation and regrowth after physical damage to roots/shoots.
- Their ability to reproduce by natural cloning and/or by seeds.
- Their value as food, shelter, cover, and nesting and resting areas for wildlife.
- Their ability to create islands of soil fertility by fostering an accumulation of organic matter, detritus, and nutrients.
- Their ability to withstand traffic stresses (e.g., as on recreational area trails and picnic areas).
- Their resistance to insects, diseases, and other pests.
- Their compatibility with the erosion control grasses and legumes used to initially stabilize the site.
- Their relative maintenance requirements and costs.

Without exception, the permanent shrubs and tree species that are finally selected must be adapted to the problem soils found at the site; this is the most cost-effective approach for after-the-fact use on CWP/DOA sites.

264. Selection and genetic manipulation of plant species for tolerance to mineral stresses in problem soils. In Section IV, attention was focused on the physical modification of various problem soils in order to improve the chances of their successful revegetation. A second and perhaps the most effective strategy is the selection and genetic manipulation of plant species for tolerance to various mineral and associated stresses in problem soils (Baker 1976). Both of these approaches must be used, however, in order to establish cost-effective revegetation protocols for problem soil environments.

265. Current thinking on the tailoring of plants to fit problem soils is that soil test calibrations are needed for selected plant species and cultivars, in concert with the determination of those soil limitations that may be economically modified or conditioned to permit the growth of plant species that have been selected or bred for tolerance to various problem soils (Baker 1976).

266. Up to the present time, notable success has been reported in selecting lovegrasses having tolerance to toxic levels of soil aluminum and iron deficiencies in calcareous soils, and in the breeding and selection of barley varieties having tolerance to very high levels of salinity (Foy, Voight, and Schwartz 1980; Foy 1983a, 1983b).

267. Source of seeds. Certified named varieties of adapted seeds should be used when available. The source of adapted seeds should correspond to the SCS land resource area (see Appendix B) similar to that occupied by the project site, and, in the southwestern United States, not in excess of approximately 300 miles south or about 200 miles north of the site. Movement east or west may be greater or less depending on changes in elevation and precipitation. The seed should be harvested from stands that are reasonably pure and produce offspring having growth characteristics that are representative of the species (Thornburg 1979).

268. Use of single species versus mixtures. Several factors influence the selection of a single species or mixtures. These can include the degree of maintenance required, the desire to have the planting visually compatible with the surrounding vegetation, and the long-term planned use of the site. Thornburg (1979) has stated that public demand, or in some cases legislation,

is focused on diversity. The species selected must be compatible in the mixture. In addition, species that may be compatible on one site may not be, at least to the same degree, on a different site (Thornburg 1979). Single or mixtures of grasses normally will require more maintenance nitrogen fertilizer than mixtures of grasses and legumes. Legumes fix atmospheric nitrogen in their roots and release the nitrogen in a form available to companion grasses in the mixture. The Europeans have been successful in promoting the creation of nitrogen cycles in derelict land (Bradshaw et al. 1982). The application of these principles to project sites should be considered. Legumes can readily accumulate 45 to 134 lb of nitrogen per acre annually if provided with appropriate conditions (Bradshaw et al. 1982). The use of legumes in mixtures with grasses will therefore reduce the need and cost of expensive supplemental nitrogen fertilizers. In essence, a self-sustaining vegetative cover could be established at the site. While nitrogen needs can be satisfied with legumes included in grass mixtures, there may still be a need for maintenance applications of lime phosphorus and potassium fertilizer to sustain a healthy vegetative cover if these materials are limiting in the problem soil (Bradshaw et al. 1977). Excellent advice on grass-legume mixtures can be obtained from the SCS plant material specialists and the US Forest Service reforestation specialists (see Appendix G).

269. Use of adapted native species versus introduced species. Native species should be given preference and used rather than introduced species if they satisfy land management objectives and adequately restore critical areas. Research comparing seed mixtures of native, introduced, and a combination of native and introduced species has suggested that combination seed mixtures provide for quick establishment and rapid production from the introduced component, while long-term production and species diversity may be ensured by the native species in the mixture (Doerr and Redente 1983). Some studies have shown that native species can equal introduced species for erosion control and forage production on reclaimed areas over several years (Redente et al. 1981; Doerr, Redente, and Sievers 1983).

270. Use of adapted ecotypes and cultivars. The following discussion of ecotypes is quoted verbatim from Thornburg (1979):

An ecotype is a population of plants that has become genetically differentiated in response to selection pressures exerted by site conditions and spatial or other breeding isolation mechanisms. Each ecotype reflects the conditions of elevation, precipitation, temperature, growing season, and soil and site conditions of its origin.

Species may have restricted ranges of distribution or grow naturally over large areas. A widely distributed species may occupy many sites or may be restricted to specific soil types or moisture conditions within its range. The species is almost invariably made up of numerous ecotypes, often with narrow ranges of adaptation. Though an ecotype may be grown over a wide area, satisfactory performance may be restricted and the maintenance of a self-perpetuating stand limited to a small geographic area or to specific sites.

The term cultivar refers to a named and released assemblage of plants. It is an international term derived from a cultivated variety, and is used to avoid confusion with the concept of the botanical variety, varietas. The latter is a category below that of species. The available cultivars of native plants are mostly selected ecotypes that exhibit superior performance for defined areas. The areas of adaptation follow the principles for those of native ecotypes, though the range of adaptation is often greater.

The actual selection of the proper ecotype or cultivar of an improved plant is as important as the selection of a native species. The western area experience of the Soil Conservation Service during the last 40 years has been that an ecotype can be moved about 250 to 300 miles (400 to 480 km) north or 100 to 150 miles (160 to 240 km) south of the point of origin to areas of comparable soils and moisture and give satisfactory performance. Movement east or west may be greater or less depending on changes in elevation and precipitation. Some species, especially cool season plants, have wider ranges of ecological amplitude and perform satisfactorily over wider ranges of conditions. Materials moved further from the point of origin do not maintain themselves in competition with local ecotypes of the same or other species. The same obvious responses are that plants moved northward grow a larger proportion of the available growing season than local ecotypes, and are generally leafier. These perform well until moved too far north to produce a seed or fruit crop, or suffer winter injury. Plants moved southward do not utilize the growing season available, are usually less vigorous, and are more susceptible to disease. Some species are sensitive to day length, which may limit north-south movement.

271. Undesirable species. Care should be taken in selecting herbaceous and woody species whose growth habits are incompatible with the long-term land uses of the site, or when, upon escape (i.e., as airborne seeds), inadvertently become undesirable weeds. Nonweedy species should be used that are adapted to

suppresses transplanted seedlings. However, black locust has been established with fair to good success when it is seeded with herbaceous species. Shrub lespedeza that is direct-seeded with herbaceous species usually will produce some plants, but planted seedlings will become established more rapidly.

Seeding herbaceous species on areas made ready for seeding in late spring, summer, and fall may present some problems with the subsequent establishment of trees, because normally, the trees will not be planted until the following spring. By then, the herbaceous vegetation may be so well established that it would adversely affect the establishment of the newly planted trees.

Following are several options for seeding and planting that may be helpful in avoiding or reducing the severity of herbaceous competition on planted trees:

Option 1. For spring seeding and planting (March 1-April 15): Plant trees and sow the following mix: Weeping lovegrass two lb/acre; K-31 fescue eight lb; Korean and/or Kobe lespedezas 12 lb; sericea lespedeza 12 lb. Do not use any of the cool-season quick cover species.

Option 2. For late spring and summer seedings (April 15-August 1): Do not sow the permanent herbaceous species but sow one or two of the quick-cover summer annuals (such as Sudan X sorghum or millet) at 1-1/2 to 2 times the rate recommended when used with mixtures. These annual plants will die in the fall leaving a mulch over winter. The following spring, plant the trees and sow one of the recommended permanent mixtures. Also apply some additional fertilizer (i.e., 50 lb/acre N, 50 lb/acre P_2O_5).

Option 3. For late summer and fall seedings (August 1-November 15): Attempt late fall or winter planting of trees into the recommended fall seeding mixture. OR sow a recommended seeding mixture but cut the seeding rate of fescue in half and plant trees the following spring.

Option 4. On areas that can be traversed with farm machinery, plant alternate bands of herbaceous vegetation and rows of trees. The use of a grain or grass drill and a pull type fertilizer spreader would be best for establishing the grass and legume vegetation in uniform bands. The bands of herbaceous vegetation could be about five to eight feet wide. A three to four foot strip should be left between the bands of herbaceous vegetation in which the trees would be planted. Conceivably, the width of the bands could be

Spacing of trees

For outslopes, woody seedlings usually are planted with a uniform spacing over the entire slope. An alternate method that may improve stabilization and erosion control is to plant the seedlings closely together (four to five feet apart) in paired rows on the contour. The paired rows should be spaced about five to six feet apart. The seedlings in one row should be spaced so as to alternate with the seedling spacing in the other row. The distance between pairs of rows should be about 20 to 24 feet. This type of planting pattern also provides desirable habitat for wildlife, especially when shrubs are used.

Following are the number of trees [required] per acre at various spacings:

5' × 5' = 1,740	7' × 7' = 890
6' × 6' = 1,200	6' × 9' = 805
6' × 7' = 1,035	8' × 8' = 680
6' × 8' = 905	8' × 10' = 545

302. Combination plantings of grasses, forbs, and woody plants. Information presented below is applicable to the eastern United States and is quoted verbatim from USDA, Forest Service (no date).

Herbaceous - woody competition. Woody species planted alone provide very little site protection or erosion control during the first few years after planting. Therefore, herbaceous vegetation must be quickly established to control erosion even though reforestation is the land use objective. Herbaceous vegetation normally is detrimental to the survival and growth of planted and direct-seeded trees, especially if the trees are planted into an established stand of grass or legumes.

A desirable practice is to plant the trees and herbaceous vegetation together at the same time, but even then a good stand of herbaceous vegetation will reduce survival and growth of the trees.

Research has shown that tree growth was suppressed the most in dense cover dominated by K-31 fescue. But, in herbaceous cover that after three years become dominated by a legume, the growth of trees was actually enhanced. Ideally, then, a legume should be established as soon as possible. Weeping lovegrass establishes cover quickly and seems to be less competitive than K-31 fescue with trees. Therefore, in the herbaceous mixture for spring planting with trees, about one-half of the fescue could be replaced with one or two pounds/acre of weeping lovegrass. Then, too, more Korean lespedeza and less sericea lespedeza could be used as shown in Option 1 on the next page.

Herbaceous vegetation usually suppresses the establishment of direct-seeded woody species even more than it

are in a loosened condition due to frost-heaving. In test seedings, tilling usually was not as important from February 15 to April 1 as it was at later dates. However, after weathering through several spring and summer rains most soils become compacted or crusted over and must be tilled before seeding is done. Actually, tilling a seedbed becomes more necessary with each successive seeding date after the March 15 to April 1 period. Seedings made in the summer and fall often will fail on soils that are not tilled, but will be successful on tilled areas.

301. Planting shrubs and trees in humid climates. The information given below is for eastern humid regions and is quoted verbatim from USDA, Forest Service (no date).

> Seedlings of trees and shrubs are usually hand planted, using either a mattock or planting bar for making the holes. The planting hole should be large enough to allow the roots of the seedling to spread out and not be crooked or doubled under. [Soil] should be firmly pressed around the planted seedling. On larger, relatively flat areas that are free of stones, a tractor-drawn tree planting machine could be used. However, hand planting is required on steep slopes and small areas.
>
> Trees should be planted within two weeks after delivery or "heeled in" the ground. The seedlings must be kept moist until they are planted. A hot dry wind can damage and kill exposed tree roots in just a few seconds. Hybrid poplars are propagated from cuttings. The cuttings can be planted with a mattock, planting bar or specially designed pointed steel bar. At least two-thirds of the hybrid poplar cutting should be in the ground. The buds should point upward.
>
> Establishment of most woody species by direct seeding has not been successful. However, black locust, bristly locust and shrub lespedeza usually can be successfully seeded. The locust should be seeded at a rate of two to three pounds per acre, the lespedezas at five to 10 pounds per acre. Fertilizing with phosphorus greatly helps establishment of direct seeded locust and lespedeza. Direct seeding of pine has been only partially successful in eastern Kentucky. Therefore, direct seeding of pine is not yet recommended as a standard practice.
>
> Season of planting
>
> Trees should be planted between March 1 and April 15 for the best results. Fall planting can be done from November 1 to January 1 depending on weather conditions. Fall planting may be less successful than spring planting due to seedling loss by frost heaving.

applying seed and fertilizer and then following with a light harrowing or with a cultipacker.

Seeding equipment and methods. Normally, there is no "best" method for applying seed. The main requirement is that the seed be evenly distributed on a good seedbed.

The hydroseeder is widely used and desirable because it can place seed on outslopes and highwalls where most other types of seeders cannot reach. However, for seeding benches and leveled areas, a cyclone seeder, a grass drill, aircraft, etc. can be just as effective. In fact, spreading seed "dry" has some advantages in that the entire load in the seeder is payload and not mostly water as with the hydroseeder. Dry-mixing seed and fertilizer together and spreading with a conventional lime-spreading truck is an efficient method for covering large areas. The Estes One-Way Blower attached to lime trucks increases their versatility and "reach" on strip mines. There may be some problem in calibrating the rate of dispersal so that both seed and fertilizer are being applied at about the proper rates. However, this equipment is being successfully used for seeding and fertilizing strip mines in eastern Kentucky.

Aircraft are useful for seeding large areas. The requirement for seeding 15 days after grading will probably preclude use of aircraft, except where catch-up seeding of large acreage is needed after the winter exemption period.

Soils that are free of stones and level enough for use of farm equipment could be seeded with a grass or grain drill. One advantage of using a drill is that all of the seed is placed in the soil and covered. Thus, less seed is needed because most of the seed is placed in a micro-environment that favors germination and seedling establishment. Tillage or scarification of a seedbed usually is not necessary prior to seeding with a drill.

A good seedbed is essential for the successful establishment of seedbed vegetation, both herbaceous and woody. Usually, preparing a seedbed is done by some form of tillage or scarification of the soil/regolith surface. Except for the winter period, an ideal situation is to seed the soils immediately after they have been graded thereby taking advantage of a ready-made seedbed. For preparing a seedbed, "front blading" with a bulldozer provides some advantage over "back blading" because the impressions left in the soil by the dozer tracks provide microsites that favor seed germination and seedling establishment. However, with either method of grading, it is best to seed immediately after the grading is finished because most soil/regolith materials will crust over or harden after [drying out following a rainfall].

Late winter and early spring seedings often can be successful without preparing a seedbed because the soils

296. Arid and semiarid climates. Seeds may be planted by either drilling or broadcasting but under semiarid and arid conditions drilling is recommended for the following reasons:

- The seed is covered to a proper depth.
- The seed is uniformly distributed.
- Rate of seeding is controlled.
- Soil firming can be done with the packer wheels attached to the drill (USDA, Forest Service 1979a and 1979b).

297. In the arid and semiarid climates, broadcasting is considered less efficient because the seeds often perch on top of the soil where germination and establishment are difficult, if not impossible. Rodents and birds may pick up broadcast seed and eat them or carry them away to a seed cache. Seeds that are broadcast should always receive some mechanical treatment to give suitable coverage unless the bed is loose so that the natural sloughing of soil will cover the seed. It is recommended that planting be done on the contour to trap available moisture and prevent erosion.

298. If the site is too steep or rocky for conventional equipment to till however, the surface should be roughed in some other way, such as a clodbuster to loosen the soil crust and allow the seed to come in contact with the soil. Broadcast seeding is sometimes satisfactory without seedbed preparation, if the soils are seeded immediately after they are graded and before the surface becomes crusted.

299. Numerous types of drills and broadcasters are on the market for use in arid regions. Selection of specific equipment will depend on their availability, capability, characteristics of the site, and treatment required. Further details on drills and other equipment for arid and semiarid regions are listed in USDA, Forest Service (1979b) and USDA, SCS (1973).

300. Humid climates. The following information on seeding equipment and seeding methods for humid regions is quoted directly from USDA, Forest Service (no date).

> A disc, bog harrow, spring tooth harrow, spike tooth harrow, flexible (English) harrow, or even ripper teeth on a bulldozer or grader can be used for tillage. Sometimes if the tilled soil is too cloddy or rough, it may pay to smooth it...with a harrow or log drag before seeding. Normally, it will be necessary to till the soil only before the seed is broadcast. Although, for areas planned for agricultural use, more intensive preparation could be used such as discing and harrowing before seeding,

with plant growth (i.e., during the frost-free times). Additional assistance can be obtained from the Plant Materials Specialists of the Soil Conservation Service in appropriate regions (see Appendices B and G).

294. For best results, bare-root and earth-balled shrubs and trees (i.e., dormant plants) should be planted in the spring, immediately ahead of the highest rainfall intensity, and as soon as severe winter temperatures have subsided. Container-grown woody seedlings can usually be planted at any time of year, provided they have been "hardened-off" or toughened for at least 2 to 3 weeks prior to planting by exposing them to cool temperatures or witholding soil moisture. In the use of container-grown woody seedlings, it is essential that they be of sufficient age to withstand subfreezing temperatures. Unfortunately, no standards exist for the proper size or age of container-grown seedlings that can withstand freezing injury (USDA, Forest Service 1979a and 1979b).

Methods of seeding and planting

295. Methods of seeding erosion control vegetation on project sites will vary depending on topography, type of vegetation, stoniness of soil surface, and equipment availability. Currently used seeding methods and their specific suitability are:

- Hydroseeders are very useful for applying seed, fertilizer, and mulch to steep slopes and other areas where equipment accessibility is limited.
- Aircraft are especially useful for broadcast seeding on large areas, inaccessible areas, and during thawing and freezing periods.
- Cyclone seeders are well suited for broadcasting seed on level areas. Germination can be increased by limiting equipment travel over seeded areas.
- Grass or grain drills are limited to rolling or level terrain that is relatively free of stones. The Rangeland drill is sturdier than conventional drills and provides better and longer performance on critical area soils.
- Rear-mounted blowers can be attached to lime trucks to spread both seed and fertilizer on steep slopes and other inaccessible areas.
- Hand planting generally is used when bare-root seedlings of trees and shrubs are planted. The method is time-consuming and therefore costly.

Table V-3

Time to Plant, Semiarid Timing Matrix

(USDA, Forest Service 1979b)

	Spring		Summer		Fall[1]		Winter	
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Direct seeding[2] (grasses)	Cool season species only	Winter moisture variable	Warm season species. More reliable precipitation. Plant prior to July-Aug rains	None	None	Frost heaving. Limited fall growth	None	Unsuitable for germination and growth
Bare root (shrubs)	Not recommended		Plant after initiation of summer rains. Soil moisture must be near saturation	Timing critical. Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	
Containerized seedlings (shrubs)	Not recommended		Soil moisture must be near saturation	Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	

PROVIDED BY EARL ALDON

Climate Summary: Semiarid mesas and valleys of northwestern New Mexico and northeastern Arizona are characterized by low, highly variable rainfall and high summer temperatures. Highest rainfall months are July and August with occasional late summer storms extending into September. Driest months are May and June. Rainfall varies with elevation, but in lower areas averages 7-10 inches annually. Snowfall light most years and seldom remains on ground. Growing season ranges from 140-180 days.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded [soils] where natural sloughing will cover the seed.

Table V-2

Time to Plant, Great Basin Range (Plant Growth Regions E and I) and Foothills, and Colorado Plateau Timing Matrix (USDA, Forest Service 1979a and 1979b)

	Spring		Summer		Fall[1]		Winter
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	
Direct seeding[2]	Favorable temperature/ precipitation for seedling establishment	Late winter may reduce time available for seeding. Late frost or a short spring may reduce seedling establishment or growth	Not recommended		Seeds may receive needed cold treatment and germinate in late winter	Early winter may prevent completion of seeding operations	Not recommended
Bare-root planting	Plant can establish if planted before summer drought	A short spring season may reduce survival	Not recommended		Plant mid-fall. Avoid late fall planting	Frost heaving in heavy soils. Open winters	Not recommended
Transplanting container-grown plants	Best results for establishment are in spring. Hazards of seed germination and establishment are bypassed	Weather may be a problem in scheduling field work	Possible if can be planted in moist soil. Long period of planting is possible	High temperatures and drought can be detrimental	Best results for establishment. Plant early to mid-fall	Frost heaving. Open winters	Not recommended

PROVIDED BY CY McKELL

Climate Summary. An area of isolated mountain ranges and extensive level valleys where a highly variable frost-free growing season may be from 120-180 days in the valleys and less than 110 days in the foothills. Spring and fall temperatures are generally moderate (50° F), but high summer temperatures may reach in excess of about 98° F. Warm season precipitation from erratic thunder-showers is less than half of the total precipitation of about 6-16 inches annually.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded [soils] where natural sloughing will cover the seed.

Table V-1

Time to Plant, Northern Great Plains (Growth Region A) Timing Matrix (USDA, Forest Service 1979a and 1979b)

	Spring		Summer		Fall[1]		Winter	
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Direct seeding[2]	Most optimum conditions probable between early March and late April. Seedlings must emerge before start of spring rains. Topsoil receives best protection at this time	Access can be a problem		Optimum planting conditions have passed would require irrigation. Postpone seeding to fall	Provides best access and weather for planting. Stratification important to native and shrub seed. More time available to plant	Topsoil and seedbed protection a problem		Seeding on snow is possible but wind may destroy seedling. Seedbed preparation and access are difficult
Bare root	Essential to plant early between frosts and snowstorms so that roots will develop before buds break dormancy. Plant immediately prior to maximum soil moisture season	Timing is very critical		Storage a problem. Seed dormancy broken. Soil too dry. Plants will burn. Lack of necessary moisture	Plants can be planted when dormant and become better acclimated to site if planted after frost	Some species not adapted to fall planting	Not recommended	
Containerized	Most optimum conditions exist very early in spring between frosts and snowstorms	Disadvantage is that stock is usually not ready or available. Access sometimes a problem	Not recommended		Same as above	Same as above	Not recommended	

PROVIDED BY R.C. HODDER

Climate Summary Considered a continental climate, with warm summers and cold winters. Temperatures can range from -40° F to +105° F. Average precipitation about 12 inches, but can vary from 4 to 18 inches annually in various localities. Precipitation dependent on snowmelt and spring rains that fall between April and mid-June. High wind and high evaporation rates common.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded [soils] where natural sloughing will cover the seed.

These mulches act to improve water infiltration into soil and promote the overall growth of roots of trees and shrubs. Care must be used to maintain the proper depth of shrub mulch, and to renew it as it decomposes with time, in order to protect the population of feeder roots that invade the mulch. This type of mulch will obviate the need for use of expensive hand weeding and the use of chemical weed control measures. Advance planning is required, however, to provide the requisite amounts of compost. In special situations, the use of chemical control measures for weeds and black polyethylene film as mulch may be justified on small-sized areas.

Time of seeding and planting

290. General considerations. An examination of baseline data dealing with the climatic regimen of the site and several years of temperature/precipitation records will aid in determining the most favorable seeding and planting periods. This information can be related to the amount of time needed for plant establishment.

291. Baseline data will help indicate if a climatic region is subject to false plant growth starts; for example, the region may have early precipitation that wets the soil and initiates seed germination, followed by a long, dry period. Of course, this information will be very general and weather conditions may vary in the planting year under study, thus causing a change in planting times (USDA, Forest Service 1979c).

292. Specific considerations. If the optimum planting dates are exceeded because of extreme weather or other conditions, the area should be seeded to one or more fast-growing annual species such as wheat, rye grass, millet, rye, and grain sorghums. Tables V-1 through V-3 list the advantages and disadvantages of various times of planting relative to: (a) direct seeding of grasses, forbs, and shrubs; (b) transplanting of bare-root shrubs and trees; and (c) transplanting of container-grown seedling stock for the northern Great Plains (Table V-1), the Great Basin range and foothills and Colorado Plateau (Table V-2), and the semiarid mesas and valleys of northwestern New Mexico and northeastern Arizona (Table V-3) (i.e., areas where saline and sodic soils are dominant).

293. Irrespective of the climatic region and the critical area, the general rule is to plant erosion control grasses and legumes immediately ahead of the highest expected rainfall probability. Precipitation probability tables are available for use in the selection of a seeding date compatible

crusting occurs. The general sequence of tilling and fertilizing the site to be revegetated is: (a) primary tillage with disk, harrow, or by hand; (b) fertilizer application; (c) mixing of fertilizer with soil; (d) application of inoculant to seeds; and (e) planting of seeds, cuttings, rhizomes, sprigs, plugs, seedlings (bare-root tree and shrub seedlings), and container-grown seedlings. For woody plants, cluster planting (or landscape planting) that follows the land morphology is recommended over that of planting in neatly spaced rows across the site (USEPA 1976).

Seedbed preparation

286. Grasses and legumes used in revegetating project sites are established by direct seeding on a properly prepared seedbed. Woody plants, such as shrubs and trees, are established by seedling transplants. However, some woody species can be seeded directly. It is recommended that the soil/regolith materials to be vegetated be analyzed to determine the proper lime and fertilizer requirements (see pages C-2 and C-3). Various seedbed problems and required treatments are discussed below.

287. Irrigation as a temporary measure. Irrigation should be used only as a temporary measure to ensure the initial establishment of herbaceous and woody vegetation in arid, semiarid, and subhumid regions. Temporary irrigation can also be used to aid in leaching salts from the saline soils found in arid, subhumid, and humid climates. The amount and frequency of irrigation depends on the availability of funds and labor, the water requirements of the particular plant species, the amount and intensity of natural precipitation, and the chemical and physical makeup of the soil materials at a specific CWP site. Information on optimal temporary watering regimes for excavated materials varying widely in age is not available. Details on the particular irrigation and management practices for saline soils are presented in US Salinity Laboratory Staff (1954) and USDA, Forest Service (1979a and 1979b).

288. Cultivation and weed control. Cultivation such as roto-tilling, disking, and harrowing may be a necessary weed and surface crust removal practice on failed (i.e., nonvegetated) areas, or on areas inadvertently left unplanted for 3 to 6 months. Such cultivation should be done when the soil is dry enough to prevent compaction and clod formation.

289. Cultivation for weed control around transplanted shrubs and trees is best avoided by resorting to the initial use of generous amounts of composted (i.e., well-decomposed) leaves, twigs, sawdust, a related mulches.

is usually very low or deficient in the soils on most project sites and is needed to establish the usual grass-legume mixtures. Before legumes are planted, the seed should be treated with the proper inoculant to ensure the presence of nitrogen-fixing bacteria. Inoculating bacteria for particular legumes are commercially available.

280. Forbs having known adaptabilities to various problem soil environments are listed in Appendix E.

281. Shrubs and trees. Various shrubs are available for planting on critical areas. Although they are primarily useful as wildlife habitats, browse, and for aesthetic purposes, some species have been developed that can help to effectively stabilize the soil. For example, bristly locust can be seeded directly. It provides good surface cover and is a rapid thicket former on acidic soils. Another advantage in using bristly locust is that it is a legume. Other commonly used shrubs include autumn olive and amur honeysuckle.

282. Trees have limited uses as soil stabilizers during early periods of growth. Their less extensive root system, as well as their slow and upright growth habit, severely limit their effectiveness in stabilizing soil. Trees should be used in combination with grasses and legumes to provide long-term protective cover. The grasses and legumes provide the necessary protection in the early years while the trees develop their protective canopies and build up a stabilizing litter of dead leaves on the ground.

283. Once established, trees can provide an effective screen as well as a habitat for wildlife. Trees also represent a renewable, marketable natural resource.

284. Shrubs and trees having known adaptabilities to various problem soil environments are shown in Appendix E.

Establishment of Plant Materials

285. Establishment of the preselected plant materials requires physical (e.g., tillage) and chemical (e.g., fertilizing, liming, etc.) seedbed treatments, which are conducted after land treatment and soil conditioning work is done, and just prior to planting. This will improve the success of vegetative stabilization of the project site. Establishment will commence as soon as possible after the specified structural and other erosion control measures (e.g., terraces, diversions, etc.) are fully in place, and before soil

will grow during the summer as well as into spring and fall (e.g., crownvetch).

274. Grasses. Grasses are particularly well suited for stabilizing exposed problem soils at project sites. They are highly adaptable to various site conditions and provide a quick, dense, and lasting ground cover. Furthermore, the dense, fibrous roots of grasses securely anchor the soil and allow surface water to infiltrate more rapidly. Grasses commonly used in stabilizing exposed soils in the humid regions include tall fescue, weeping lovegrass, and redtop. Other grass species and their characteristics are given in Appendix E for various problem soils.

275. Among grass species, a high degree of adaptability to various site conditions exists. Species are available for different exposure (sunlight, temperature, and wind) conditions, and for planting during the spring, summer, and fall. Some species are highly tolerant of wet soils, while others do well on dry, droughty soils.

276. The ability of many grasses to spread themselves by surface and underground runners (stolons and rhizomes) is another important aspect. Given time and proper maintenance, these grasses are able to heal minor breaches in the ground cover resulting from erosion, plant disease, and other factors.

277. Forbs. Forbs are defined as the nonleguminous and leguminous plant species used in combination with various grasses. Legumes are the most widely chosen of the forbs primarily because the soil bacteria Rhizobium forms nodules on the roots, fixes atmospheric nitrogen, and, through the symbiotic relationship with the legume, supplies it with a usable source of nitrogen for its growth processes. Upon death and decomposition of the legume, the nitrogen becomes available to nonnitrogen-fixing plants in the seed mixture and thereby promotes their growth.

278. Nonleguminous forbs such as annual sunflower (humid climate) and evening primrose (arid and semiarid climates) are examples that are receiving increased attention and use on problem sites. Nevertheless, legumes such as the lespedezas, clovers, and birdsfoot trefoil are the predominant forbs that are chosen for combinations or mixtures with grasses because of their more extensive availability.

279. Legumes have a large taproot that extends deep into the soil and enhances both soil stabilization and infiltration. When legumes are planted, less nitrogen fertilizer is required to maintain the ground cover. Nitrogen

the problem soil environment (USDA, Forest Service 1937). The potentially weedy plants should only be used in areas that are far removed from prime farmlands.

272. Other selection factors. The following items should also be considered in plant materials selection:

- Potential fire risk of plant materials.
- Adaptability to south-slope exposures versus north-slope exposures (aspect or exposure affects solar radiation loads, light quality, day length, and growing season length).
- Presence of animals and birds that will aid in seed dispersal (e.g., some plant species are totally dependent on animals for seed dispersal).
- Adaptability of plant materials to habitats at increased elevations (generally, as elevation increases, the length of the growing season decreases).

Plant materials grouping and terminology

273. Reference is frequently made throughout this report to grasses and forbs (i.e., herbaceous vegetation) on the one hand, and to woody plants (trees and shrubs) on the other. Herbaceous vegetation is nonwoody, and may be grouped in the following ways to reflect the time of planting and soil temperature preferences:

- Grouped by season (one or multiple).
  - Rapid-growing annual (i.e., temporary cover) species--annual grasses and forbs; these materials provide cover for only one growing season.
  - Permanent (perennial) cover species--perennial grasses, legumes, and forbs; these provide cover for more than one growing season.
    a. Short-lived perennial.
    b. Long-lived perennial.
- Grouped by temperature preference for best growth.
  - Rapid-growing (temporary cover) species--warm season preference; these produce seed in late spring and summer months, then die; or will regenerate each year from seeds (e.g., annual lespedeza); quick cover species may be winter annuals (rye) or summer annuals (sundangrass), and some of the summer annuals will produce cover from midsummer seedings.
  - Permanent (perennial cover) species--cool-season grasses and forbs; these grow best when planted in very early spring and in the autumn; some may become dormant (Kentucky bluegrass) during very hot summers, while others

controlled by broadcasting the seed and fertilizer onto strips of tilled soil material. The bands and rows should be laid out on the contour to reduce runoff and erosion in the alternate strips without herbaceous cover. This procedure would provide adequate ground cover for erosion control and yet afford minimum competition to tree seedlings regardless of the season when the herbaceous species were sown.

Plantings for wildlife. Combination plantings of grasses and legumes with shrubs and trees are very desirable for wildlife cover and food. Grasses such as switchgrass, wheat, the sorghums and millets, and legumes such as the clovers and lespedezas produce seed for song and game birds. Shrubs such as autumn olive, shrub lespedezas, tatarian honeysuckle and silky dogwood provide fruit, browse, or cover for a variety of wild creatures. Some trees, such as black locust, flowering dogwood, and bur oak provide food and cover for wildlife.... Strip plantings of herbaceous plants, shrubs, and trees are more attractive than solid plantings. An example of a preferred pattern is one with strips of grasses and legumes 30-to-50 feet wide alternating with strips of shrubs and trees of similar width.

Tree-shrub combinations. Combination plantings of trees with nitrogen-fixing shrubs offer one approach for improving the growth of desirable tree species (Coppin and Bradshaw 1982). Shrubs such as autumn olive or shrub lespedezas should be planted in alternate rows with the trees. An advantage of using shrubs (instead of nitrogen-fixing trees like black locust) as nurse plants is that the shrubs will not overtop the slower growing commercial trees. Nor will the shrub be as likely to injure the small trees by "whipping" action such as occurs with fast developing locust crowns.

Mulches

303. Mulching is essential on most critical areas and slopes. Commonly used mulches are listed and described in Appendix F. The application of plant residues or other suitable mulch materials to the soil surface helps to:

- Prevent erosion, both by water and wind.
- Prevent surface compaction or crusting.
- Facilitate infiltration.
- Inhibit evaporation (which may also slow upward movement of salts through soils).
- Provide proper soil temperatures.

- Be compatible with plant development, improve germination conditions, protect seedlings.
- Possibly add desired seeds while acting as a mulch.
- Reinoculate microorganisms into excavated materials.

304. No one mulch will meet all of these criteria; it should be determined which attributes are most important in a particular situation and the mulch that most nearly satisfies user needs chosen (USDA, Forest Service 1979a and 1979b). Mulch materials and chemical stabilizers used in hydromulching/hydroseeding operations are discussed in Section VI.

Vegetative Maintenance

305. Proper management and maintenance of a restored site are vital to maintaining its stability. Considerations of protection needed at the site; methods to evaluate and nurture the vegetation resource; and provisions for special emphasis areas (recreation, wildlife, grazing, crop production, and forestry) should be included in the site improvement (USDA, Forest Service 1979a and 1979b).

General considerations

306. A restored site should be protected, at least initially, whenever the vegetation on the site may be threatened by livestock, wildlife, invading weeds, or human traffic. Animal use of restored sites can be compatible with vegetation establishment and maintenance. Site restoration plans that include use of the site by animals can be successful as long as it is realized that restored areas may be more sensitive than adjacent land, and that special standards govern their rehabilitation. For example, seeded areas sometimes will attract animals such as deer in numbers sufficient to damage the stand. Rodents and rabbits can also damage the vegetation. The animals are attracted by the lushness and palatability of the planted vegetation. Thus, if pressure from animal invasion becomes too great, steps should be taken to protect the site (USDA, Forest Service 1979a and 1979b).

Specific considerations

307. A variety of techniques are successful for protecting the site against grazing livestock; however, indirect methods of keeping livestock away from a site are less costly than direct methods. The following information on

methods for protecting against livestock and wild animals is quoted directly from USDA, Forest Service (1979a and 1979b).

> Indirect methods for protecting a site against livestock include:
>
> a. Adding less palatable species to the seed mixture;
>
> b. Salting away from the seeded area - no closer than one-fourth mile;
>
> c. Providing permanent water away from the seeded area; fencing out nearby water;
>
> d. Adjusting the use of livestock on the site to allow plants to mature by using a temporary alternative area for grazing, or by requiring non-use during seedling establishment;
>
> e. Moving livestock off the area when allowable use is reached on the revegetated site.
>
> Direct methods include:
>
> a. Barriers. Metal or wood fences, varying from wire fences to brush piles are effective.
>
> b. Repellents. Those used to repel browsing deer and elk have some effectiveness on sheep and cattle; however, specific repellents to discourage livestock use have not been fully developed.
>
> c. Herding. This requires the use of herders to keep animals contained on areas other than those recently restored.
>
> To protect the site against overuse of vegetation as food and habitat by animal wildlife, various techniques are successful.
>
> Indirect methods for protecting a site against wild animals include:
>
> a. Using plant species that are undesirable to deer and elk.
>
> b. Using plant species that mature about the same time as native species.
>
> c. Avoiding hay as mulch where it may attract big game.
>
> d. Controlling the deer population through hunting permits, particularly in localized areas during plant establishment.
>
> Direct methods for protecting a site against wild animals include:
>
> a. Barriers. Metal, plastic, or wood devices, varying from woven wire fence to brush piles, which

prevent browsing can be used. Four to six inch diameter plastic tubing placed over trees or plants to be protected have been effective in the Northeast. Woven wire fences eight feet high are recommended to exclude antelope, deer, and elk.

b. Repellents. The effectiveness of repellents depends on the plant species to be protected and the availability of other vegetation in the area. It has been found that repellents may not be effective when the vegetation is being irrigated. Apparently, the lushness of the vegetation is so attractive to the animals that the repellents do not deter them. Specific repellents to discourage rabbits and rodents have not been fully developed.

c. Herding. This can be achieved with noisemakers, such as metal cans or acetylene guns. Lights and mirrors have also been used, as have tethered dogs.

d. Poisoning. Rodents can be controlled by poisoning. Check State and Federal regulations on use of poisons.

e. Encouraging predator invasion. Roosts, rock piles, etc., will provide a habitat for predators and thus control small mammal populations.

Weeds

308. Weeds may have to be removed from a restored site for a variety of reasons: they may present a fire hazard, especially along roads; are aesthetically displeasing; are noxious; or provide too much competition with desired plants. Both mechanical and chemical means can be employed. In general, chemical means should be used only in highly selective situations such as for control of noxious weeds (USDA, Forest Service 1979a and 1979b).

Insects

309. The use of insecticides may need to be considered. Before making any attempt to control insects, one should know (a) the name of the insect one wants to control; (b) the dangers of using chemicals to control insects; and (c) whether the harm caused by the insects is sufficient to warrant use of an insecticide (USDA, Forest Service 1979a and 1979b).

Refertilization

310. It is possible that a refertilization and reliming program will have to be established to ensure that the site receives sufficient nutrients to sustain the established vegetation, particularly where domestic grasses and

legumes are concerned. In general, the fertilizer requirements of native species would be lower than that for domestic grasses and forbs.

311. Several methods can be used to determine refertilization/reliming needs: soil tests, tissue tests, observing deficiency symptoms, greenhouse testing, and field plots. Soil tests are an important method for identifying nutrient deficiencies, with the exception of nitrogen, which is best detected by onsite observations or tissue tests. Greenhouse and field tests can supplement these methods. When using soil analysis for lime and fertilizer requirements, rely on qualified suggestions of state soil testing labs or commercial labs and follow recommended procedures for soil sampling (USDA, Forest Service 1979a and 1979b).

Structural measures

312. Periodic inspection of all structural measures is required to reveal problems in order that modifications, repairs, cleaning, or other maintenance operations can be performed. Any necessary repairs must be prompt to prevent further damage, and measures should be taken to prevent a reoccurrence of the problem and ensure continued stabilization of the restored area. Recommendations for maintenance of structures are usually included in their design specifications.

Special emphasis areas

313. Sometimes unsatisfactory stands are obtained from seeding efforts, and sometimes good young stands are lost or partly lost due to drought, frost heaving, landslides, grazing, etc. Sometimes stands that at first appear too thin will improve with a little more time and improving weather conditions. In some cases, it is necessary to repeat the job in whole, or in part. This should not be neglected. Analyze the situation carefully, try to determine the cause of failure and devise means to improve chances for success.

314. From 2 to 5 years may be required for a stand to become established in arid and semiarid areas. Often plantings that were thought to be a failure at the end of the seeding year may develop into excellent stands. Plantings should not be destroyed until they have been thoroughly examined by someone familiar with the identification of seeds and seedlings. Seeds may germinate 1 or 2 years after seeding if moisture was not available earlier. The seeds should be examined to determine whether they have germinated (Thornburg 1979).

SECTION VI: NONVEGETATIVE STABILIZATION PRACTICES

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315. Nonvegetative as well as vegetative practices are used to stabilize critical areas. It is difficult to separate the two because they are often used together. If vegetation can provide adequate long-term soil protection, long-term nonvegetative stabilization is not required. Where vegetation will provide partial protection, as is often the case in areas subject to concentrated flow (such as found in a drainageway), both types of stabilization are desirable. If vegetation cannot provide any protection, such as on the bottom or bed of a stream, nonvegetative stabilization is the only protective treatment available.

316. Nonvegetative stabilization covers a wide assortment of short- and long-term soil stabilization practices, which vary considerably in cost-effectiveness and ability to withstand erosional stresses. As a general rule, it is probably best to use measures that have proven successful in the field. New products or practices appearing worthwhile and offering possible cost advantages should be demonstrated on test plots before being employed extensively.

Types and Uses of Nonvegetative Soil Stabilizers

Short-term measures

317. Mulching and chemical stabilization are two major types of short-term, or temporary, nonvegetative soil stabilizers. Both are employed to provide protection against excessive soil erosion for periods of less than 1 year.

318. Mulching. Mulches of organic materials such as straw, hay, woodchips, wood fiber, and other conventional short-term materials are the most popular means of providing short-term soil stabilization. Mulch is used in the establishment of a vegetative ground cover to protect the seedbed from excessive erosion prior to germination of the seeds and until the new vegetation is sufficiently established. The mulch provides a favorable environment for seed germination and plant development. Mulches can also be used in place of short-term vegetative stabilizers to protect temporarily against excessive soil loss prior to the preparation of a seedbed. A more detailed discussion of organic mulches can be found in Appendix F.

319. Water dispersible mulches and tacks: hydromulching and hydroseeding. Water dispersible mulching materials and tacks are used for hydroseeding operations. The most frequently used mulching materials (singly or in various combinations) are wood-cellulose fibers; a 50-50 mix of ground newsprint and corrugated papers (borates removed); various powdered gums; liquid styrene-butadiene copolymer emulsions; and defibered grass or cereal straws (Kay 1979; USEPA 1976).

320. The term hydroseeding means the hydraulic application of a slurry of plant seeds and water to problems soils. Fertilizers, limestone, mulch materials, and chemical tacks and binders may also be present in the pumped slurry. Tables VI-1 and VI-2 summarize information on chemical tacks and binders. Comparison of certain water dispersible mulches and stabilizers is shown in Table VI-3. According to Bradshaw and Chadwick (1980), the wood cellulose fiber ranks equally to jute netting for soil stabilization and to straw mulch for level of persistence.

321. The term hydromulching applies only when a water dispersible mulch material is hydraulically spread onto a problem soil (Kay 1978; USEPA 1976; USDA, Forest Service 1979b). Table VI-4 summarizes information on hydroseeding and hydromulching experience in the State of California. The cost and effectiveness of hydroseeding/hydromulching vary. Alternative methods should be considered since the most expensive approach is not necessarily the most effective. According to Kay (1978) "straw plus tackifier is more effective for both erosion control and plant establishment than many of the more expensive treatments" (see Table VI-4). Under some conditions, a rough seedbed or covering the seed may be the best approach to establishment of protective vegetation (Kay 1978).

322. The most important consideration for any hydromulching material is that it must stick to the soil and hold the seed on steep slopes against high wind and rainfall intensities (Kay 1978). But it is equally true that these same qualities may prevent the seed from readily falling into natural depressions (microsites) and becoming covered with soil, thereby promoting a higher stand density (Kay 1978).

323. Another problem arises when the germination of legume seeds is inhibited by fertilizers containing moderate to high concentrations of certain soluble salts (e.g., ammonium sulfate and sodium nitrate) in the slurry. When

Table VI-1

Summary of Chemical Binders and Tacks (US Environmental Protection Agency 1976)

	Uses					
Name	Temporary soil stabilizer	Mulch	Mulch tack	Description	Application method	Manufacturer or product information
Aerospray® 52 Binder	X	X		Water dispersible, alkyd emulsion. Nontoxic. Nonphytotoxic. pH 8-9	Any nonair-entraining equipment (as for liquid fertilizer, asphalt emulsions, and water).	American Cyanimid Company Industrial Chemicals and Plastics Division Wayne, New Jersey 07970
Aerospray® 70 Binder	X	X	X	Water dispersible, liquid polyvinyl acetate emulsion	Hydroseeder. Seed, fertilizer, and wood fiber may be applied with product.	American Cyanimid Company Industrial Chemicals and Plastics Division Wayne, New Jersey 07970
Aerospray® 72 Binder	X	X	X	Water dispersible, liquid alkyd emulsion resin.	Hydroseeder. Seed, fertilizer, and wood fiber may be applied with product.	American Cyanimid Company Industrial Chemicals and Plastics Division Wayne, New Jersey 07970
Aquatain	X	X		Water dispersible. Nontoxic. Nonflammable.	Hydroseeder or any nonair-entraining equipment. Seed and fertilizer may be applied with product	The Larutan Corporation 1424 South Allec Avenue Anaheim, California 92805
Curasol® AE	X	X	X	Water dispersible, polyvinyl acetate copolymer emulsion. Nontoxic. Nonphytotoxic. pH 4-5	Hydroseeder or any nonair-entraining equipment.	American Hoechst Corporation 1041 Route 202-206 North Bridgewater, New Jersey 08876
Curasol® AH	X		X	Water dispersible, high polymer synthetic resin. Nontoxic. Nonphytotoxic pH 4-5.	Hydroseeder or any nonair-entraining equipment. Seed and fertilizer may be applied with product.	American Hoechst Corporation 1041 Route 202-206 North Bridgewater, New Jersey 08876
DCA-70	X	X	X	Water dispersible, polyvinyl acetate emulsion. Nontoxic. Nonphytotoxic Nonflammable. pH 4-6	Hydroseeder or any nonair-entraining equipment.	Union Carbide Corporation Chemicals and Plastics 270 Park Avenue New York, New York 10017

(Continued)

Table VI-I (Concluded)

Name	Uses: Temporary soil stabilizer	Uses: Mulch	Uses: Mulch tack	Description	Application method	Manufacturer or product information
Genequa 169	X			Water dispersible, modified liquid acrylic resin.	Hydroseeder. Seed, fertilizer, and wood fiber may be applied with product.	The Delta Company Charleston, West Virginia
Liquid Asphalt			X	Asphalt cement that is dispersed or suspended in water or various solvents.	Hand-spray nozzle or an offset distributor bar attached to an asphalt distributor truck.	Asphalt Institute Asphalt Institute Building University of Maryland College Park, Maryland 20740
M-145	X			Water dispersible, liquid resin polymer.	Hydroseeder. Seed and fertilizer may be applied with product.	The Dow Chemical Company Midland, Michigan 48640
Petroset® SB	X	X	X	Water dispersible oil emulsion. Nontoxic. Nonflammable. pH 6.0 ± 0.5	Any spraying equipment.	Phillips Petroleum Company Chemical Department Commercial Development Division Bartlesville, Oklahoma 74003
Terra Tack	X	X	X	Water dispersible, powdered vegetable gum	Hydroseeder or, for dry application, standard hopper spreaders (as for fertilizers or lime).	Grass Growers, Inc. P.O. Box 584 Plainfield, New Jersey 07061
Urea Formaldehyde Foam		X		Urea-formaldehyde resin plus a foaming agent, mixed and foamed with compressed air, then applied to soil. Wetting agent is then applied to the foam. Seed and fertilizer sprayed on top.	Nonair-entraining equipment for resin and foam. Hydroseeder for seed and fertilizer.	U.F. Chemical Company 37-20 58th Street Woodside, New York 11377
XB-2386	X			Water dispersible, liquid reactive polymer	Injected into slurry at the nozzle of a hydroseeder	3M Company Adhesives, Coatings and Sealers Division, 3M Center Saint Paul, Minnesota 55101

Table VI-2

Application Rates For Selected Binder and Tacks*

Name	Rate
Aerospray 52 Binder	On steeply inclined, exposed slopes - 1 gal/100 ft^2 - concentrated. On seedbed - 30-45 gal (concentrate) per acre in dilution ratios varying up to 10 parts water to 1 part chemical.
Aerospray 70 Binder	On steeply inclined, exposed slopes - 0.5 to 1.5 gal/ mixture per sq yd. Mixture can have ratios ranging from 7 to 20 parts water.
Aerospray 72 Binder	
Aquatain	Mixture - 5.5 parts water to 1 part aquatain. Approximately 3 gal aquatain, plus required water, per 1000 sq ft of surface area is normally required for most soil surfaces.
Curasol AE	Flat areas - 30 gal to 1000 gal water for moist soils, 2000 gal - dry soils. 3:1 - 2:1 slopes - 40-55 gal to 1000 gal water for moist soils, 2000 gal - dry soils. 1.5:1 slopes - 55-65 gal to 1000 gal water for moist soils, 2000 gal - dry soils. Swales and ditches - 90-100 gal to 1000 gal water for moist soils, 2000 gal - dry soils.
Curasol AH	For straw mulch tack - 30-45 gal to 150-300 gal water with mulch blower, 300-500 gal water with hydroseeder per acre. For hay mulch tack - 20-30 gal to 150-300 gal water with mulch blower, 300-500 gal water with hydroseeder, per acre.
DCA-70	Soil stabilizer - 1:1 ratio with 0.5 or more gal/ sq yd. Chemical mulch - 1 part to 20 parts water, 0.5 gal/ sq yd - perm. soils. Tack - 1 part to 10-20 parts water, disperse 330-950 gal of solution per acre depending on strength. Each acre should have 30-45 gal of concentrate.

(Continued)

* Clar et al. (1981).

Table VI-2 (Concluded)

Name	Rate
Liquid Asphalt	Mulch - spray rate - 0.15-0.30 gal/sq yd. Tack - spray rate - 0.1 gal/sq yd. Spray rate emulsified - 0.04 gal/sq yd.
M-145	On steeply inclined, exposed slopes - 1.5 to 2.0 gal/sq yd of mixture. Mixture usually ranges from 5 to 10 parts water for every part chemical.
Petroset SB	Highly variable - depends on different soil textures, desired penetrations, and intended usages. In general, the greater the dilution ratio, the deeper the penetration and the weaker the binding strength for a given soil condition. Specific applications and cost formulas and nomographs are furnished by the manufacturer.
Terra Tack	Stablizer - wet - 50 lb in 2000 gal water with seed per acre. Dry - 86 lb/per acre with seed. Mulch tack - long fiber mulches - 1:20 mix ratio - apply 1000 gal/acre. Short fiber mulches - 1:40 mix ratio - apply 2000 gal/acre.

the fertilizers were omitted from the slurry, the germination of hydroseeded legume seeds was excellent (Bradshaw and Chadwick 1980, p 86).

324. The problem reported in the first example could best be resolved by first broadcasting or drilling the seed, followed by the application of a quality hydromulch (Kay 1978, p 6). In the second example relating to the fertilizer-inhibition of legume seed germination, the recommended solution was to apply the mineral fertilizer 3 to 6 weeks after the initial hydroseeding (Bradshaw and Chadwick 1980). Other factors generating concern in hydroseeding/hydromulching practices are (USDA, Forest Service, 1979b; Bradshaw and Chadwick 1980; Kay 1976, 1978):

- Often an expensive and unreliable technique.
- Hydromulches may improve germination but do not improve stand density compared to drilling followed by mulching.
- Additional nitrogen may be needed to compensate for the wide carbon:nitrogen ratio of the chosen mulch material.
- Success or failure of hydroseeding may depend on getting a good legume stand; the presence of nitrogen-fixing legumes is a must for long-term upgrading of problem soils.

Table VI-3

Comparison of Water Dispersible Mulches and Stabilizers for Initial Land Restoration*

Material	Application Rate** lb/acre	Persistence	Stabilization	Soil Moisture Retention	Nutrient	Toxicity
Stablizer/mulches						
Wood cellulose fibre (as slurry)	890-1780	OO	OOO	O	o	o
Sewage sludge (as slurry)	1780-3560	O	OO	O	O	o
Stabilizers						
Asphalt (as 1:1 emulsion)	670	O	OO	O	o	O
Latex (as appropriate emulsion)	178	O	OO	o	o	OO
Alginate or other collodial carbohydrate (as emulsion)	178	OO	OO	o	o	o
Polyvinyl acetate (as 1:5 emulsion)	890	OO	OO	o	o	OO
Styrene butadiene (as 1:20 emulsion)	446	OO	OO	o	o	OO

Note: OOO high; OO medium; O low; o nil.

* Modified from Bradshaw and Chadwick (1980).

** Rates can be varied depending on circumstance--will affect soil water capture and retention and seeding establishment.

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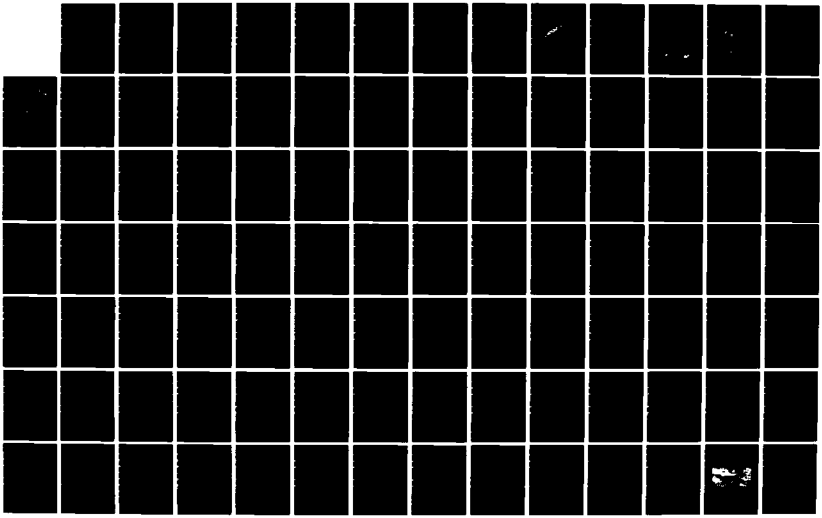

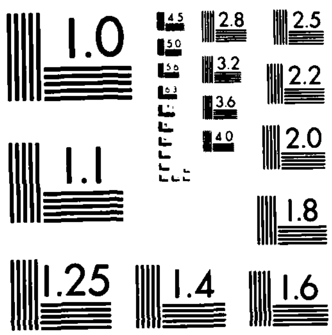

MICROCOPY RESOLUTION TEST CHART
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Table VI-4

Summary of Methods and Costs of Hydroseeding and Hydromulching in California*

Treatment	Comments	Pregermination Erosion Effectiveness**	Effectiveness on Plant Establishment**	Approx. cost per acre, $†
Hydroseeding or hydromulching (seed + fertilizer) with 500 lb wood fiber, 1500 gal water/ 3 acres.	Similar effectiveness to broadcasting seed and fertilizer. Not enough fiber to hold seed in place or produce a mulch effect. Seed distribution would be improved by increased volume of water.	1	1-4	250
Hydromulching with 1500 lb wood fiber plus an organic glue (Ecology Control, Terratack III, etc.) plus seed and fertilizer.	The addition of an orgainc glue will sometimes improve fiber holding and germination. Does not increase labor or machinery cost.	2+	3-6	550-650
Hydromulching with 2000-	Produces a true mulch effect and some	2-3	4-7	530-750

(Continued)

Note: All of the above treatments offer only minimal protection from impact of raindrops and water flowing over the surface, but are all weed-free.

* Adapted from Kay (1976).

** 1 = minimal, 10 = excellent.

† Assumes seed plus fertilizer $150.00, fiber $150/ton, Ecology Control $1.25/lb, polyvinyl acetate $3.00/gal, 1500 gal hydroseeder with 2-man crew $55.00/hr, labor $13/hr, straw $50/ton, straw mulcher with 4 man-crew $64/hr (applies 2 tons/hr) and markup of 30% for overhead (including equipment depreciation) and profit. Cost figures were derived from conversations with contractors, and by review of recent Caltrans contracts.

(Sheet 1 of 3)

Table VI-4 (Continued)

Treatment	Comments	Pregermination Erosion Effectiveness	Effectiveness on Plant Establishment	Approx. cost per acre, $
3000 lb/acre wood fiber plus seed and fertilizer.	erosion protection. Commonly better results than 1000 lb fiber or fiber plus glue.			
Seed and fertilizer broadcast and covered with soil but followed with hydromulch of wood fiber at 2000-3000 lb/acre.	Very effective, combines advantages of seed coverage and mulching.	2-3	6-8	680-865
Straw or hay broadcast with straw blower on the surface at 3000 lb/acre and tacked down (asphalt emulsion, Terratack II, etc.). Seed and fertilizer broadcast with hydroseeder or by hand.	Common elsewhere in US. Very effective energy absorber, mulch; straw forms small dams to hold some soil. May be weedy depending on straw source. Not for cut slopes steeper than 2:1. Cost would increase significantly if slopes over 50 ft from access, or application is uphill.	5-7	8-10	650
Straw broadcast 4000 lb/acre rolled to incorporate (punched) another 4000 lb straw broadcast and rolled, seeded, and fertilized. Seed and fertilizer broadcast	Common on difficult fill slopes in California. Very effective. Not possible on most cut slopes. Very weedy. Cost would increase significantly if slopes over 50 ft from access.	6-8	8-10	877-1070

(Continued)

(Sheet 2 of 3)

Table VI-4 (Concluded)

Treatment	Comments	Pregermination Erosion Effectiveness	Effectiveness on Plant Establishment	Approx. cost per acre, $
with hydroseeder or by hand.				
Roll-out mats (jute, excelsior, etc.). Held in place with wire staples. Seed and fertilize as in hydroseeding.	Some are a good mulch, weed free, adapted to small areas. Can be installed any season, cuts or fills. Unsightly. Difficult to install on rocky soils.	5-7	5-10	2400-2700
Seed and fertilizer broadcast, or hydromulched with fiber (treatment), followed by erosion control chemical such as PVA at 6:1 dilution (6 parts water) at 1000 lb solid/acre (approx. 200 gal PVA).	Very expensive, but will hold soils and seed in some very difficult conditions. May restrict penetration of water into soil. Will not cure below 55°F. Not effective on soils which crack. Will not support animal or vehicle traffic.	10+	?	1070-1370

(Sheet 3 of 3)

- Hydroseeding and hydromulching should be used in special situations such as areas that are too inaccessible or steep for conventional seed drills and other equipment and in those areas where the seed can be kept moist for 2 to 3 weeks after seeding.
- Increased rates of application of water, seed, wood fiber, and chemical tack/binder may lead to prohibitively high costs of erosion control on problem soils in arid and semiarid regions.
- Direct-seeded shrubs and herbaceous plants often do not withstand the competition from grasses used in the seeding mixture for erosion control during the initial stabilization phase on CWP sites.
- Some wood fiber and paper hydromulches may require measures to remove boric acid, borate, and other potential soil sterilants (USDA, Forest Service 1979b, Bradshaw and Chadwick 1980, Kay 1978).
- On acid problem soils, 4 to 5 tons/acre of lime material is required; about half of this amount can be applied at one time in the hydroseeder, making it necessary to spread the additional lime separately (Bradshaw and Chadwick 1980).

325. The capacity ranges for hydraulic seeding/mulching machines are between 150 and 1500 gal. Volumes of water required per acre also range from 150 to 1500 gal. The amount of wood fiber required per acre may range from 500 to 3000 lb. Recently, Kay (1978) has reported that the effectiveness of wood fiber mulch in controlling erosion and enhancing plant establishment was doubled when the wood fiber application rate was 3000 lb/acre, compared to conditions where the seed and fertilizer were broadcast and then covered with soil in the absence of wood fiber mulch. The approximate cost of the latter treatment was $320 per acre, while the addition of the wood from hydromulch treatment raised the cost to $865 per acre (see Table VI-4). However, it was shown that the pregermination erosion control effectiveness was increased threefold by use of wood fiber mulch.

326. Chemical tacks and binders. Some treatments include the use of short-term erosion control chemical binders and tacks in combination with conventional mulches and water dispersible mulches (Kay 1976). Current information on the cost-effectiveness of chemical tacks and binders under a wide range of environmental settings is limited. General information on chemical binders and tacks is given in Tables VI-1 and VI-2.

327. Chemical mulches should be used alone only when there is no other mulching material or they are used in conjunction with temporary seeding during periods when mulch is not required, or where restoration operations occur

when seeding cannot be done (Clar et al. 1981). At other times chemical tacks and binders may be used on any exposed area which is being stabilized, within permissible limits. The chemical binders may be used in arid regions and on droughty soils, but their effectiveness in lowering soil moisture evaporation rates is less than that for conventional organic mulches. Chemical binders are, however, excellent for short-term binding/tacking of conventional organic mulches. All chemical binder applications must be inspected and reapplied, if necessary, periodically up to 60 to 90 days or until the plantings have become firmly established. This is particularly needed after rainstorms that may have dislodged the chemical mulch (Clar et al. 1981).

328. Chemical stabilization. Chemical soil stabilizers are designed to coat and penetrate the soil surface and bind the soil particles together. They are used to protect bare soil slopes, not subject to traffic, from wind and water erosion during temporary establishment of seedbed. Chemical stabilizers are used in lieu of and in conjunction with temporary mulch material to provide mulch tack and soil binder. Chemical stabilizers can be applied only to a very finely prepared seedbed. Soil moisture, temperature, and texture influence the success of the application. Their limited applicability and high cost make them undesirable except where absolutely necessary. It is recommended that chemical soil stabilizers be tested on small, representative plots of ground before deciding to use them extensively. As a general rule, chemical stabilizers do not provide protection for as long a period of time as straw, hay, and other organic mulches.

Long-term measures

329. Long-term, nonvegetative soil stabilization is required when vegetation alone cannot withstand the erosional stresses imposed by surface runoff and when vegetation is not adaptable to the chemical, moisture, or traffic conditions occurring in the soil or on the surface to be stabilized. Areas requiring such treatment include waterways and toxic or excessively wet soil surfaces. Long-term measures include nonstructural methods like mulching and soil reinforcement, and structural methods such as paving, channel lining, and grade control.

330. Mulching. Mulches made of nonbiodegradable material, such as fiberglass and various plastics, protect seedbeds during the critical germination and early plant development period, and act as reinforcement following establishment of the vegetative cover. These materials include

nettings and loose, stringy products that can become securely enmeshed in the vegetation at the ground surface and in the rootmat. Proper installation by experienced personnel is vital to the success of these measures. Light applications of crushed stone or gravel can also serve as a long-term mulch. Table VI-5 contains information on specific long-term mulches (Nolan et al. 1976; Nolan, Spring, and House 1978).

331. Stone surfacing. Heavy applications of crushed stone can be used to stabilize highly toxic surfaces, or excessively wet seepage areas on slopes. Materials used include crushed stone, gravel, and slag. Crushed stone or gravel mulches retain their effectiveness indefinitely if properly applied and protected from compacting traffic. Sediment reduction is estimated at 70 to 90 percent, and nutrient runoff reduction at 50 to 70 percent. Stones 0.5 in. or greater in diameter will protect against rain splash and sheet flow and can withstand wind velocities up to 85 mph (US Department of Defense, no date).

332. Erosion control fabrics. These materials consist of synthetic fabric matting that can be used as a replacement for concrete, asphalt, and rock riprap. They allow the establishment and maintenance of vegetation where nonvegetative stabilization alone would be aesthetically unpleasing. Seed is sown into the material and grass grows through it and eventually covers it. Soil and sediment particles are held by the filaments of the mat. Installation and maintenance of these materials can be less expensive than the use of conventional materials. Claims have been made that these mats are effective on slopes up to 1:1 over a wide range of soil conditions; have successfully withstood 14 in. of rain during the first month after installation; and have stabilized both natural and artificially compacted soils. Manufacturers say these materials are thoroughly compatible with all grass varieties and other types of vegetation. "Enkamat" is the trade name of one soil reinforcement material. Figure VI-1 shows how Enkamat works. In sandy soils, an underlay of filter fabric should be used.

333. Nonwoven filter fabrics. One currently available fabric matting which appears to have been successfully used for modifying erosion of subsurface soils and the movement of riprap along stream banks and waterways is known as Stabilenka (Type 180) nonwoven filter fabric. This water-permeable material consists of a sheet of nonwoven 100 percent polyseter which is rot-resistant (biological and chemical) and is available in standard roll widths

Table VI-5

Guide To Long-Term Nonbiodegradable Mulches

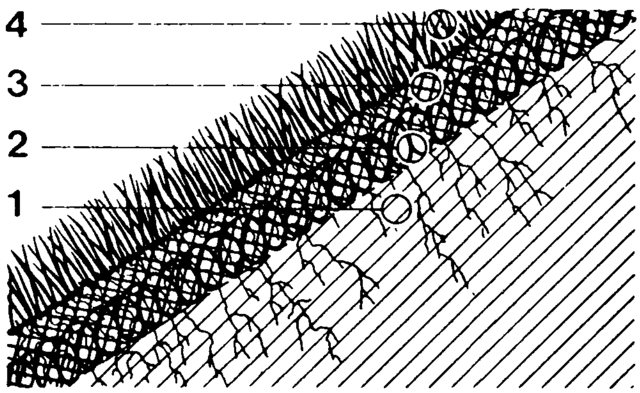
Mulch Material	Application Rate	Remarks
Crushed stone (including limestone)	~6 to 10 in. thick	Most durable (especially granite); use on problem soils prone to slipping, frost heaving, and seepage
		Limestone on acid areas will not last as long as other materials
Gravel	6 to 10 in. thick	Use on gentle slopes and flat areas only; use on problem soils prone to toxicity, seepage of water, and frost heaving
Slag	4 to 6 in. thick	By-product of steel blast furnace; uses similar to crushed stone and gravel
		Do not use with certain filter fabric (Filter-x, etc.)
Fiberglass	Blanket should completely cover the disturbed area	Use without additional mulch
	Strands applied at a rate of 850 to 1100 lb/acre	Use only on limited critical areas because of cost
		Applied as a mat or blanket, or in long strands
		Blanket form should be stapled
		Longstrands applied by compressed air spraying
		Erosion from beneath may be a problem with blanket
Enkamat, Geofab, and related synthetic fabrics	Use available sheet widths and controlled size openings. Place a 3-in. layer of sand having wide gradations of particle sizes on top of fabric prior to use of riprap.	Fabrics must be placed in intimate contact with underlying soil. On fill sites, compact the soil to 90% of the standard Proctor density before placing the fabric. Riprap <u>must</u> be used on sites where overland water flow rates exceed 10 fps.*

(Continued)

* Personal Communication, Mr. James Talbot, USDA/SCS, Engineering Division, Washington, D. C.

Table VI-5 (Concluded)

Mulch Material	Application Rate	Remarks
Riprap	Use when overland flow rate of water exceeds 10 fps	Riprap is placed on top of the underlying layer of sand which covers the synthetic fabric. The exact sand layer thickness has not been determined, but it must be placed between the fabric and the riprap.



1 = Soil Material
2 = Enkamat
3 = Sedimentation
4 = Grass Area

Figure VI-1. Enkamat installed on slopes

ranging from 42 to 84 in., and roll lengths of 1641 linear feet (American Enka Co. 1981).

334. Nonwoven polyester fabric is also available from another manufacturer; it is a water-permeable and rot-resistant fabric called Geofab. This matting is also used for modifying erosion of subsurface soils and movements of rock riprap along stream banks (Mercantile Development, Inc. 1982). Apparently both of these materials can be installed on slopes under a layer of sand or pebbles and on stream bank and bridge apron areas under layers of stone and riprap rock as a means of soil stabilization. The Geofab polyester nonwoven fabric is available in standard roll widths of 12.5 to 16.0 ft and roll lengths of 300 to 1000 ft (Types 1115 thru 1135).

335. An interesting erosion control composite for stream bank stabilization is reported for nonwoven Stabilenka when used in conjunction with woven Enkamat (American Enka Co. 1981). The former nonwoven (Type 100) polyester is placed under the Enkamat for maximum earth reinforcement on shoreline areas, bridge aprons, etc., where water flow rates and quantities have the greatest

potential for destabilizing the stream banks (American Enka Co 1981). After removing competing vegetation plus rocks, followed by suitable shaping, dressing, and compaction of the problem stream bank area, the fabrics are installed and anchored using appropriate sized staples (supplier requires a minimum length of 16 in.). A suitable seed mixture is then oversown and as the plant roots penetrate the nonwoven Stabilenka fabric, additional anchoring power is provided by the roots growing between the turf and the underlying fabric and soil (American Enka Co. 1981). Further study of the efficacy of this and related erosion control composites is required in order to establish total installation costs in different environmental settings.

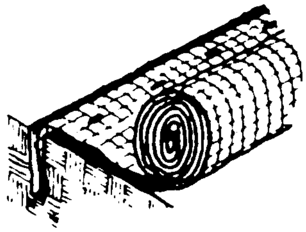
336. Current thinking holds that fabric mats are especially useful on limited and highly critical areas because of high installation costs. For example, installation costs for Enkamat range from $1.00 to $2.00 per square yard. Total installed cost for Enkamat 7020 approximates $5.50 per square yard (American Enka Co. 1981). These areas include steep slopes, stream banks, and areas of high wind velocities. Disadvantages other than expense include (USDA, Forest Service 1979b):

- High labor costs for pinning and anchoring the fabrics.
- Erosion from beneath.
- General ineffectiveness on rock areas and rough surfaces.

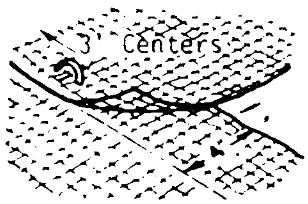
337. Polyester fabric mats (nonwoven) should be installed in accordance with the manufacture's specifications. Staples or ground fasteners may consist of plain iron wire (No. 8-11 gauge); broad wire U-staple; narrow wire V-staple; T-staple, and narrow, triangular wood survey stakes. Stake lengths may range from 12 to 18 in. depending on the expected load maxima. Staples should be placed down the mat centers at 3-ft intervals. Prior to installation of the fabric mats one must:

- Shape and grade the slope, or other area to be protected, as required.
- Remove all rocks, clods, or debris larger than 2 in. in diameter that will prevent contact between the net and the soil surface.
- When open-weave nets are used, lime, fertilizer, and seed may be applied either before or after laying the net. When nonwoven matting is used, apply the soil amendments and seed before the matting is laid (Clar et al. 1981).

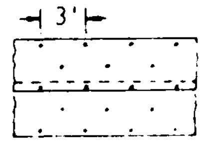
Figures VI-2 and VI-3 show how woven fabric nets and mats can be installed and oriented on special slopes and drainways.

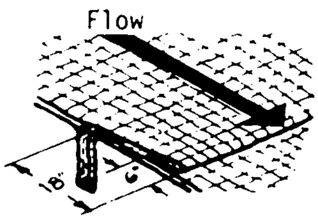


<u>Anchor Slot</u>: Bury the up-channel end of the net in a 6" deep trench. Tamp the soil firmly. Staple at 12" intervals across the net.

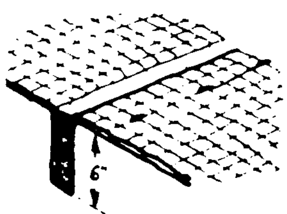


<u>Overlap</u>: Overlap edges of the strips at least 4". Staple every 3 feet down the center of the strip.

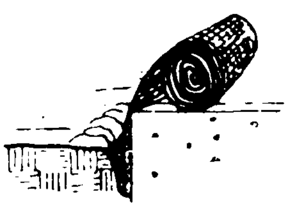




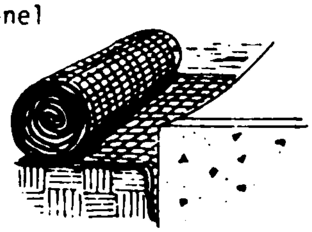
<u>Joining Strips</u>: Insert the new roll of net in a trench, as with the Anchor Slot. Overlap the up-channel end of the previous roll 18" and turn the end under 6". Staple the end of the previous roll just below the anchor slot and at the end at 12" intervals.



<u>Check Slots</u>: On erodible soils or steep slopes, check slots should be made every 15 feet. Insert a fold of the net into a 6" trench and tamp firmly. Staple at 12" intervals across the net. Lay the net smoothly on the surface of the soil - do not stretch the net, and do not allow wrinkles.

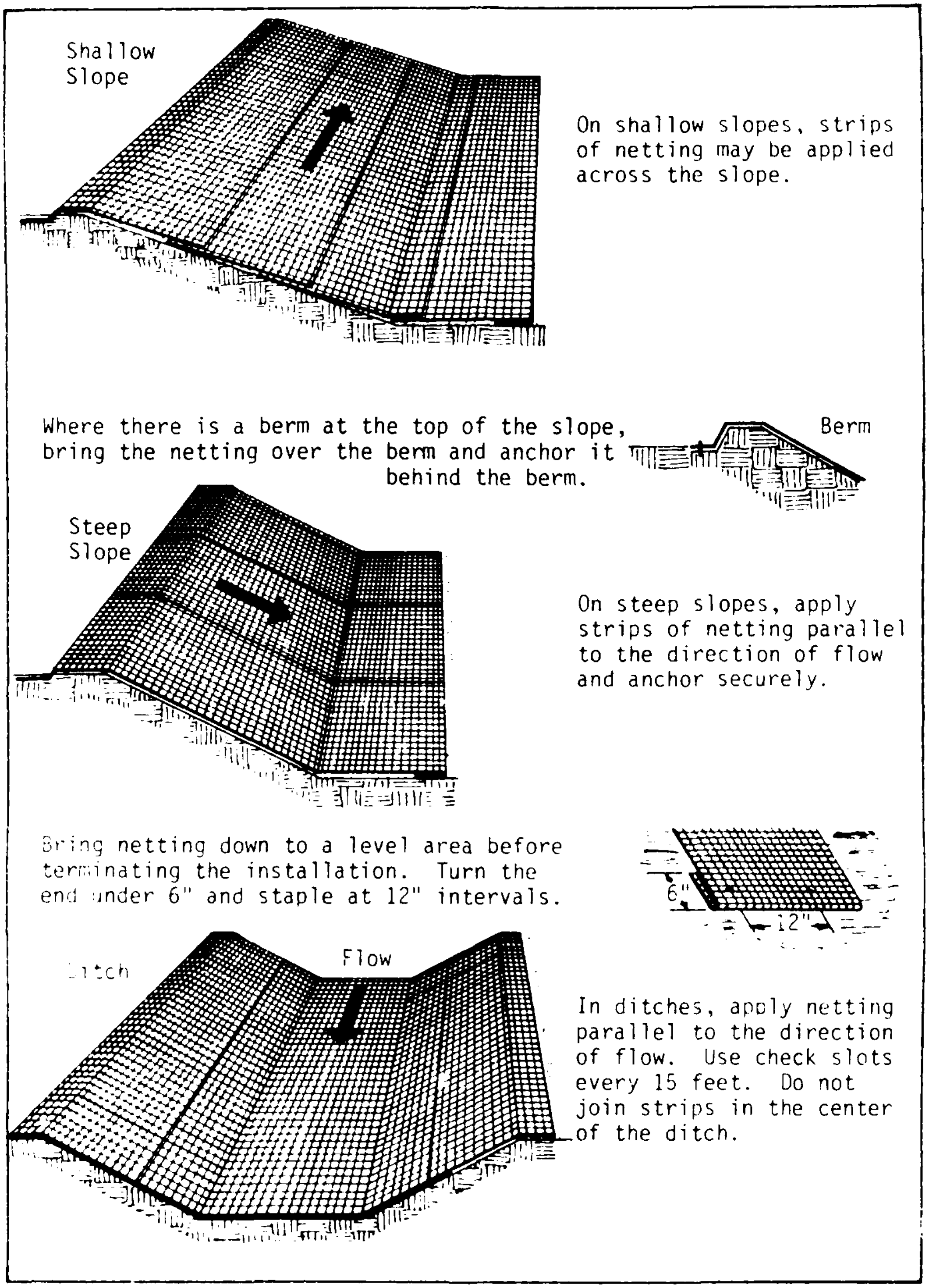


<u>Anchoring Ends At Structures</u>: Place the end of the net in a 6" slot on the up-channel side of the structure. Fill the trench and tamp firmly. Roll the net up the channel. Place staples at 12" intervals along the anchor end of the net.



Source: Adapted from Conwed Products Brochure

Figure VI-2. Installation of woven netting and matting (Virginia Soil and Water Conservation Commission 1980)



Source: Adapted from Ludlow Products Brochure

Figure VI-3. Orientation of woven netting and matting (Virginia Soil and Water Conservation Commission 1980)

338. Woven fabrics for silt fences and filter barriers. Silt fences with the various trade names are used to:

- Catch silt and sediment particles before they enter a stream or waterway, when installed at the toe of cut slopes.
- Eliminate catch basins to avoid the costly clean-outs of sediment from these basins.
- Eliminate water contamination by solids movement from storage piles to waterways.
- Slow the velocity of natural stream flows and catch suspended sediment, thereby mitigating stream bank erosion.
- Serve as a silt curtain in sedimentation ponds to prevent short-circuiting.

339. Because of the inherent limitations to higher water flow velocities in streams, silt fences should not be installed in live streams or in swales or ditch lines where flows are likely to exceed 1 cfs. Silt fences should be constructed after the cutting and slashing of trees and before excavating haul roads, fill benches, or any soil disturbing activity in the drainage areas (Clar et al. 1981).

340. Silt fences are composed of a wire support fence and an attached synthetic filter fabric to slow the water flow rate significantly but with a higher filtering efficiency than burlap. Both woven and nonwoven synthetic fabrics are commercially available. The woven fabrics generally display higher strength than the nonwoven fabrics. When tested under acid and alkaline water conditions, most of the woven fabrics increase in strength. The same is true of tests under extensive ultraviolet radiation. Permeability rates vary regardless of fabric type. While all of the fabrics demonstrate very high filtering efficiencies for sandy sediments, there is considerable variation among both woven and nonwoven fabrics when filtering the finer silt and clay particles (Clar et al. 1981).

341. The silt fence is designed generally for situations where only sheet or overland flows are expected. The installation of a silt fence is pictured in Figure VI-4. General comments on the installation of a silt fence are as follows (Clar et al. 1981):

- The height of a silt fence should not exceed 36 in. (higher fences may impound volumes of water sufficient to cause failure of the structure).

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Maintenance Consideration

350. Proper maintenance of any stabilization practice is essential for its continued effectiveness. Table VI-6 lists maintenance practices for nonvegetative measures. Judgment is required in applying various chemical stabilizers and fabric mats because their high cost dictates that their use be limited to small areas of critical and sensitive problem soils.

Table VI-6

Maintenance Practices for Nonvegetative Measures

Practice	Maintenance Procedures
Conventional mulches (biodegradable)	Inspect periodically Remulch bare spots during design life
Chemical stabilizers/tacks	Inspect periodically Reapply to bare spots during design life
Nonbiodegradable mulches and fabrics	Inspect periodically Reapply where necessary Fiberglass and plastic mats should be checked for erosion underneath the blanket
Stone surfacing	Inspect periodically Reapply where necessary
Soil reinforcement materials and erosion control fabrics	Inspect after each storm until vegetation has been established and look for undercutting of material Inspect periodically after vegetation has been established
Channel stabilization	Inspect periodically and repair according to SCS standards and specifications for each practice
Streambank stabilization with fabric matting	Inspect after each storm and look for undercutting and other dislocations of fabric mats

possible. Where sustained, heavy flow is not present, revetments constructed of loose stone riprap, or thin, stone gabions provide an environment for the growth of vegetation within the armored portion of the channel.

346. Unlike revetments, which can be used to protect the entire channel or its sides or bottom, check dams are designed to protect only the base, or bottom, of the channel from erosion. These structures are placed across the channel at intervals along the alignment to inhibit physically the moving water from eroding the bottom of the channel. They generally consist of a relatively narrow strip of stone riprap laid across the channel. Logs and lumber are also used to construct check dams. These structures are used to control erosion in ditches, and other constructed drainageways, having steep gradients or long grades.

347. Channel stabilization structures, such as revetments, and check dams found in ditches, diversions, and streams must be frequently inspected for damage. Repairs must be prompt to prevent further costly damage, and measures should be taken to prevent a reoccurrence of the problem (USEPA 1976).

348. Additional information on the design and maintenance of long-term nonvegetative measures can be found in Appendix D. Section IV of this manual contains information on channel linings for waterways.

Design Considerations

349. Design considerations for nonvegetative stabilization practices should be based on dependable site-specific information compiled during site evaluation procedures and the recommendations of the interdisciplinary team. Sources of information useful on these items are as follows:

Practice	Source
Mulches (conventional organic)	Section VI of this manual and USDA, Forest Service (1979b).
Chemical stabilizers	USEPA (1976)
Mulches for hydroseeding	Details in this section
Soil reinforcement fabrics	American Enka Co., Enka, N. C. Mercantile Development, Inc., Westport, Conn.
Channel stabilization	Appendix D of this manual and SCS District Offices
Streambank stabilization	American Enka Co.; Mercantile Development, Inc.

be removed manually. The sediment removed should be placed in an area where there is little danger of erosion.

- The silt fence should not be removed until adequate vegetative growth ensures no further erosion of the slopes. Generally, the fabric is cut at ground level; the wire and posts removed; and the sediment spread, seeded, and protected (mulched) immediately (Clar et al. 1981).

343. Channel stabilization materials. Channel stabilization, for the most part, involves the use of stone riprap and other durable materials to stabilize ditches and other small-scale, man-made waterways. This is necessary where channel velocities exceed safe velocities for vegetated lining due to increased grade or a change in channel cross section, or where durability of vegetative lining is adversely affected by seasonal changes.

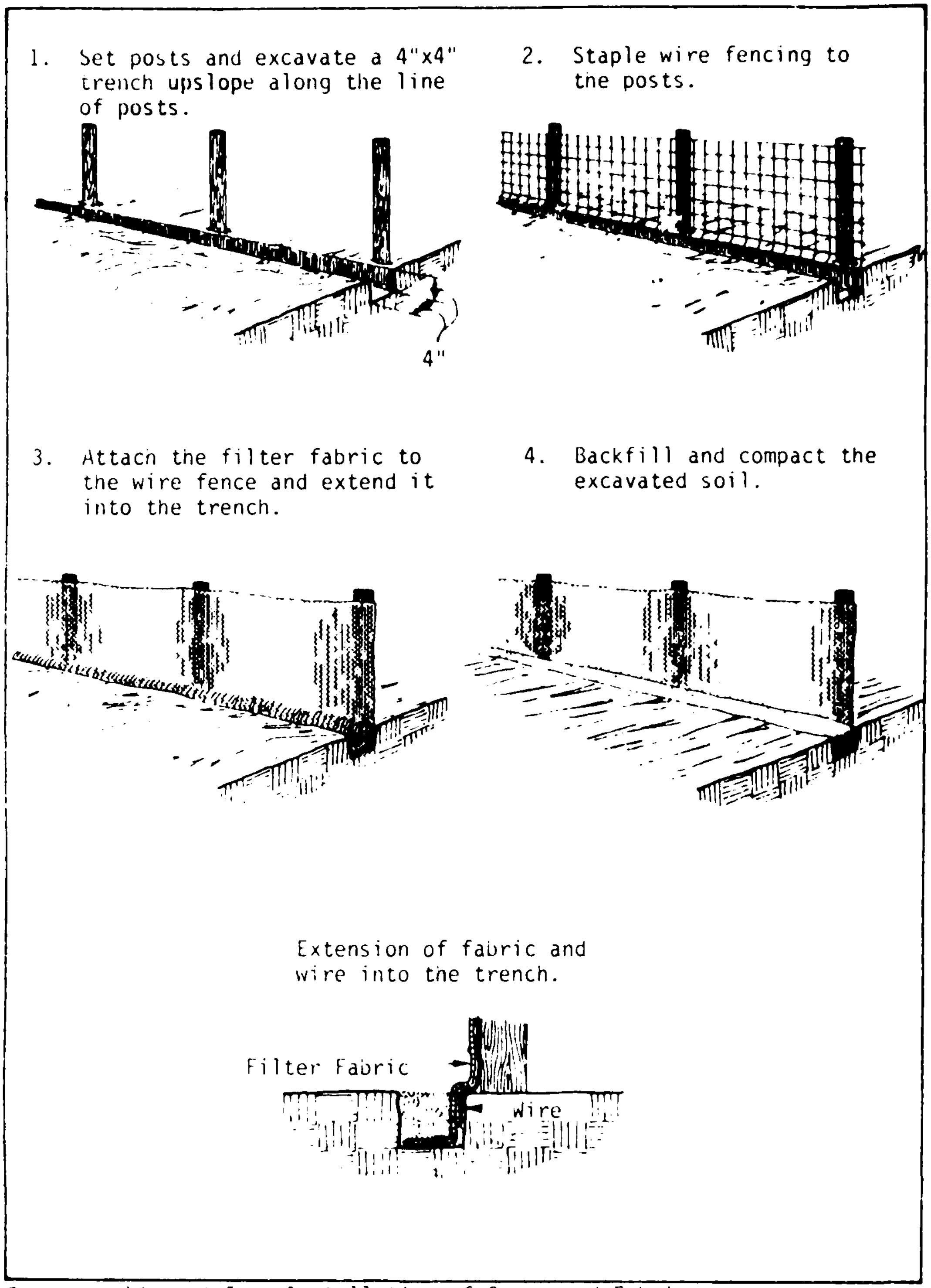
344. Channel stabilization structures are used to maintain ditch or channel alignment (i.e., prevent erosion of the sides of the channel) and/or maintain channel gradient (i.e., prevent scour of the channel bottom). Revetments and check dams are the structures most commonly used to prevent channel erosion. Revetments are designed to shield the channel from the hydraulic and abrasive action of concentrated flow. Generally, these structures are built of stone riprap placed in the bottom of the channel at critical locations to prevent downcutting. Where the sides of the channel cannot be stabilized with vegetation alone, the stone is carried up the sides of the channel to form a complete channel lining. The stone riprap should be sandstone, limestone, or other durable rock of a size that cannot be removed by the runoff. Large voids between rock fragments should be linked with smaller fragments to provide a dense cover. When heavy or sustained flows must be handled, a graded sand and stone filter, or filter cloth, should be placed under the structure securely against the soil surface to prevent the upward movement of soil particles due to hydraulic action. Wire baskets filled with stone (gabions), various concrete blocks, bags filled with a mixture of sand and cement, and nylon mattresses filled with a sand/cement grout (Fabriform ®) are also used to construct revetments in waterways. These products and materials are generally used only to stabilize highly critical areas, such as natural streams or stream alignments. Where good riprap stone is not available at the site, cost considerations may warrant the use of certain material in ditches and other areas in place of stone riprap (USEPA 1976).

345. For environmental and aesthetic reasons and to minimize maintenance requirements, vegetation should be used with structures whenever

- The filter fabric should be purchased in a continuous roll cut to the length of the barrier to avoid the use of joints. When joints are necessary, filter cloth is spliced together only at a support post, with a minimum 6-in. overlap, and securely sealed.
- Posts are spaced a maximum of 10 ft apart at the barrier location and driven securely into the ground (minimum of 12 in.). When extra strength fabric is used without the wire support fence, post spacing may not exceed 6 ft.
- A trench is excavated approximately 4 in. wide and 4 in. deep along the line of posts and upslope from the barrier.
- When standard strength filter fabric is used, a wire mesh support fence is fastened securely to the upslope side of the posts using heavy duty wire staples at least 1 in. long, tie wires, or hog rings. The wire extends into the trench a minimum of 2 in. and does not extend more than 36 in. above the original ground surface.
- The standard strength filter fabric is stapled or wired to the fence, and 8 in. of the fabric is extended into the trench. The fabric does not extend more than 36 in. above the original ground surface. Filter fabric should not be stapled to existing trees.
- When extra strength filter fabric and closer post spacing are used, the wire mesh support fence may be eliminated. In such a case, the filter fabric is stapled or wired directly to the posts.
- The trench is backfilled and the soil compacted over the filter fabric.
- Silt fences are removed when they have served their useful purpose, but not before the upslope area has been permanently stabilized (Clar et al. 1981).

342. Inspection and maintenance requirements for silt fences include the following:

- Silt fences should be inspected periodically for damage such as tearing by wind, animals, or equipment and for the amount of sediment which has accumulated.
- Silt fences and filter barriers should be inspected immediately after each rainfall and at least daily during prolonged rainfall. Any required repairs should be made immediately.
- Should the fabric on a silt fence or filter barrier decompose or become ineffective prior to the end of the expected usable life and the barrier still be necessary, the fabric should be replaced promptly.
- Sediment deposits should be removed after each storm event. Also, they must be removed when deposits reach approximately one half the height of the barrier. In situations where access is available, machinery can be used; otherwise, it must



Source: Adapted from Installation of Straw and Fabric Filter Barriers for Sediment Control, Sherwood and Wyant

Figure VI-4. Construction of a silt fence (Virginia Soil and Water Conservation Commission 1980)

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APPENDIX A: GLOSSARY

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Pan: Horizon or layer in soil that is strongly compacted, indurated, or very high in clay content. See Claypan, Fragipan, Hardpan.

Parent material (soils): The unconsolidated, more or less chemically weathered mineral or organic matter from which the solum of soils has developed by pedogenic processes. The C-horizon may or may not consist of materials similar to those from which the A- and B-horizons developed.

Particle size: The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

Perennial plant: A plant that normally lives three or more years.

Permeability, soil: The quality of a soil horizon that enables water or air to move through it. The permeability of a soil may be limited by the presence of one nearly impermeable horizon even though the others are permeable.

pH: Logarithm of the reciprocal of the hydrogen ion concentration. Neutral is pH 7.0. All pH values below 7.0 are acid, and all above 7.0 are alkaline.

Phreatophyte: A plant deriving its water from subsurface sources; commonly used to describe nonbeneficial, water-loving vegetation.

Planting season: The period of the year when planting or transplanting is considered advisable from the standpoint of successful establishment.

Plant succession: The process of vegetation development whereby an area becomes successively occupied by different plant communities of higher ecological order.

Puddled soil: A dense soil dominated by massive or single-grain structure, almost impervious to air and water; resulting from handling a soil when it is in a wet, plastic condition so that when it dries it becomes hard and cloddy.

Rangeland: Land on which the native vegetation (climax or natural potential) is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing or browsing use. Includes lands revegetated naturally or artificially to provide a forage cover that is managed like native vegetation. Rangelands include natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows.

Range seeding: Establishing adapted plant species on ranges by means other than natural revegetation.

Reclamation: Rebuilding a site to allow habitation or organisms originally present in approximately the same composition and density.

Reconnaissance: A preliminary inspection or survey of an area to gain general information useful for future management.

Regolith: The unconsolidated mantle of weathered rock and soil material on the earth's surface; loose earth materials above solid rock.

Microrelief: Small-scale local differences in topography, including mounds, swales, or pits that are only a few feet in diameter and with elevation differences of up to 6 ft.

Mineral soil: A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter, usually containing less than 20 percent organic matter but sometimes containing an organic surface layer up to 30 cm thick. See Organic soil.

Mitigation (wildlife): The reduction or elimination of damages to fish and wildlife resources.

Mottled (soils): Soil horizons irregularly marked with spots of color. A common cause of mottling is impeded drainage, although there are other causes, such as soil development from an unevenly weathered rock. The weathering of different kinds of minerals may cause mottling.

Mulch: A natural or artificial layer of plant residue or other materials, such as sawdust, straw, leaves, bark, sand, or gravel, on the soil surface to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc.

Multiple use: Harmonious use of land for more than one purpose, i.e., grazing of livestock, wildlife production, recreation, watershed, and timber production. Not necessarily the combination of uses that will yield the highest economic return or greatest unit output.

Native species: A species that is part of an area's original fauna or flora.

Natural revegetation: Natural re-establishment of plants; propagation of new plants over an area by natural processes.

Niche: A habitat that supplies the factors necessary for the existence of an organism or species.

Nitrogen-fixing plant: A plant that can assimilate and fix the free nitrogen of the atmosphere with the aid of bacteria living in the root nodules. Legumes with the associated rhizobium bacteria in the root nodules are the most important nitrogen-fixing plants.

Noxious species: A plant that is undesirable because it conflicts, restricts, or otherwise causes problems under the management objectives. Not to be confused with species declared noxious by laws.

Nutrients: (1) Elements, or compounds, essential as raw materials for organism growth and development, such as carbon, oxygen, nitrogen, and phosphorus. (2) The dissolved solids and gases of the water of an area.

Organic matter: Decomposition products of plant and animal materials such as litter, leaves, and manure.

Organic soil: A soil that contains a high percentage (greater than 20 or 30 percent) of organic matter throughout the solum.

Litter: (1) In forestry, a surface layer of loose organic debris in forests, consisting of freshly fallen or slightly decomposed organic materials. (2) In waste, that highly visible portion of solid waste that is generated by the consumer and is carelessly discarded outside of the regular disposal systems; accounts for about 2 percent of the solid waste volume.

Loess: Soil material transported and deposited by wind and consisting of predominantly silt-sized particles.

Macronutrient: A chemical element necessary in large amounts (always greater then 1 ppm) for the growth of plants; usually applied artificially in fertilizer or liming materials. "Macro" refers to quantity and not the essentially of the element. See Micronutrient.

Macroorganisms: Those organisms retained on a US standard sieve No. 30 (openings of 0.589 mm); those organisms visible to the unaided eye. See Microorganisms.

Manure: The excreta of animals, with or without the admixture of bedding or litter, in varying stages of decomposition.

Map, topographic: A representation of the physical features of a portion of the earth's surface as a plane surface, on which terrain relief is shown by a system of lines, each representing a constant elevation above a datum or reference plane.

Marsh: A periodically wet or continually flooded area where the surface is not deeply submerged; covered dominantly with sedges, cattails, rushes, or other hydrophytic plants. Subclasses include freshwater and saltwater marshes. A miscellaneous land type.

Mesophyte: A plant that grows under intermediate moisture conditions.

Microclimate: (1) The climatic condition of a small area resulting from the modification of the general climatic conditions by local differences in elevation or exposure. (2) The sequence of atmospheric changes within a very small region.

Microfauna: Protozoa and smaller nematodes.

Microflora: Bacteria, including actinomycetes, viruses, and fungi.

Micronutrient: A chemical element necessary in only extremely small amounts for the growth of plants. "Micro" refers to the amount needed rather than to its essentiality. Examples are boron, chlorine, copper, iron, manganese, and zinc. See Macronutrient.

Microorganisms: Those organisms retained on a US standard sieve No. 100 (openings of 0.149 mm); those minute organisms invisible or only barely visible to the unaided eye. See Macroorganisms.

Land capability: The suitability of land for use without permanent damage. Land capability, as ordinarily used in the United States, is an expression of the effect of physical land conditions, including climate, on the total suitability for use without damage for crops that require regular tillage, for grazing, for woodland, and for wildlife. Land capability involves consideration of (1) the risks of land damage from erosion and other causes and (2) the difficulties in land use owing to physical land characteristics, including climate.

Land resource area: An area of land reasonably alike in its relationship to agriculture with emphasis on combinations and/or intensities of problems in soil and water conservation; ordinarily larger than a land resource unit and smaller than a land resource region.

Land treatment: The stabilization of critical areas through the shaping of the land and incorporation of structural measures to prepare the site to receive other restoration/improvement measures. Land treatments are carried out at the same time as soil conditioning measures.

Leached soil: A soil from which most of the soluble materials ($CaCO_3$, $MgCO_3$, and more soluble materials) have been removed from the entire profile or have been removed from one part of the profile and have accumulated in another part.

Leaching: The removal from the soil in solution of the more soluble materials by percolating waters.

Legume: A member of the pulse family, one of the most important and widely distributed plant families. The fruit is a pod that opens along two sutures when ripe. Leaves are alternate, have stipules, and are usually compound. Includes many valuable food and forage species, such as peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu. Practically all legumes are nitrogen-fixing plants.

Legume inoculation: The addition of nitrogen-fixing bacteria to legume seed or to the soil in which the seed is to be planted.

Lime: From the strictly chemical standpoint, refers to only one compound, calcium oxide (CaO); however, the term is commonly used in agriculture to include a great variety of materials that are usually composed of the oxide, hydroxide, or carbonate of calcium or of calcium and magnesium; used to furnish calcium and magnesium as essential elements for the growth of plants and to neutralize soil acidity. The most commonly used forms of agricultural lime are ground limestone (carbonates), hydrated lime (hydroxides), burnt lime (oxides), marl, and oyster shells.

Lime requirement: The amount of agricultural limestone, or the equivalent of other specified liming material, required per acre to a soil depth of 6 in. (or on 2 million pounds of soil) to raise the pH of the soil to a desired value under field conditions.

Limestone: A sedimentary rock composed of calcium carbonate ($CaCO_3$) or calcium magnesium carbonate ($CaCO_3$-$MgCO_3$).

Herb: Any flowering plant except those developing persistent woody bases and stems above the ground.

Herbicide: A chemical substance used for killing plants, especially weeds.

Herbivore: A plant-eating animal.

Hydrophyte: A plant that grows in water or in wet or saturated soils.

Impeded drainage: A condition which hinders the movement of water through soils under the influence of gravity.

Impervious soil: A soil through which water, air, or roots cannot penetrate. No soil is impervious to water and air all the time.

Indicator plants: Plants characteristic of specific soil or site conditions.

Infiltration: The gradual downward flow of water from the surface through soil to ground water and water table reservoirs.

Infiltration rate: A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Inoculation: The process of introducing pure or mixed cultures of microorganisms into natural or artificial culture media.

In situ: In place. Rocks, soil, and fossils that are situated in the place where they were originally formed or deposited.

Interaction: Mutual or reciprocal action or influence between organisms, between organisms and environment, or between environmental factors.

Interceptor drain: Surface or subsurface drain, or a combination of both, designed and installed to intercept flowing water.

Interdisciplinary approach: An analysis method which involves the application of the training and knowledge of persons from many professions in the assessment of potential impacts of Corps projects on the economy, society, and the natural environment.

Internal soil drainage: The downward movement of water through the soil profile. The rate of movement is determined by the texture, structure, and other characteristics of the soil profile and underlying layers and by the height of the water table, either permanent or perched. Relative terms for expressing internal drainage are none, very slow, medium, rapid, and very rapid.

Interseeding: Seeding into an established vegetation.

Invader plant species: Plant species that were absent in undisturbed portions of the original plant community and will invade under disturbance or continued overuse. Commonly termed "invaders."

Grass: A member of the botanical family Gramineae, characterized by bladelike leaves arranged on the culm or stem in two ranks.

Grassed waterway: A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from cropland.

Green manure crop: Any crop grown for the purpose of being turned under while green or soon after maturity for soil improvement.

Ground cover: Grasses or other plants grown to keep soil from being blown or washed away.

Ground water: Phreatic water or subsurface water in the zone of saturation.

Growing season: The period and/or number of days between the last freeze in the spring and the first frost in the fall for the freeze threshold temperature of the crop or other designated temperature threshold.

Gully: A channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains or during the melting of snow; may be dendritic or branching or it may be linear, rather long, narrow, and of uniform width. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by ordinary farm tillage. See Erosion.

Habitat: The environment in which the life needs of a plant or animal organism, population, or community are supplied.

Halophyte: A plant adapted to existence in a saline environment, such as greasewood (***Sarcobatus***), saltgrass (***Distichlis***), and the saltbushes (***Atriplex*** spp.).

Hardpan: A hardened soil layer in the lower A- or in the B-horizon caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in the moisture content, and pieces of the hard layer do not slake in water.

Hardwoods: A term applied to one of the botanical group of trees that have broad leaves, in contrast to the conifers; also wood produced by trees of this group regardless of texture.

Heaving: The partial lifting of plants out of the ground, frequently breaking their roots, as a result of freezing and thawing of the surface soil during the winter.

Heavy metals: Metals that may be present in municipal and industrial wastes that pose long-term environmental hazards; they include cadmium, cobalt, chromium, copper, mercury, nickel, lead, and zinc.

Exposure: Direction of slope with respect to points of a compass.

Fertility (soil): The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other growth factors, such as light, moisture, temperature, and the physical condition of the soil, are favorable.

Fertilizer formula: The quantity and grade of the crude stock materials used in making a fertilizer mixture; for example, one formula for a fertilizer with an analysis of 5-10-5 could be 625 lb of 16 percent nitrate of soda, 1111 lb of 18 percent superphosphate, 200 lb of 50 percent muriate of potash, and 64 lb of filler per ton.

Fetch: The unobstructed path of winds where they can gain velocity.

Field capacity: The amount of water retained in a soil or in solid wastes after it has been saturated and has drained freely. In soils also called field moisture capacity (obsolete in technical work) and is usually expressed as a percentage of the oven-dry weight of the soil. In waste management also called moisture-holding capacity.

Flocculate: To aggregate or clump together individual, tiny soil particles, especially fine clay, into small clumps of granules.

Flora: The sum total of the kinds of plants in an area at one time.

Fragipan: A natural subsurface horizon with high bulk density relative to the solum above, seemingly cemented when dry but showing a moderate to weak brittleness when moist. The layer is low in organic matter, mottled, slowly or very slowly permeable to water, and usually shows occasional or frequent bleached cracks forming polygons. It may be found in profiles of either cultivated or virgin soils but not in calcareous material.

Forb: A herbaceous plant which is not a grass, sedge, or rush.

Forest: A plant association predominantly of trees and other woody vegetation.

Fungi: Simple plants that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae, which may grow together to form a visible body. Simpler fungi are involved in the stabilization of solid waste and sewage.

Gabion: A rectangular or cylindrical wire mesh cage filled with rock and used as a protecting apron, revetment, etc., against erosion.

Grade: (1) The slope of a road, channel, or natural ground. (2) The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction like paving or laying a conduit. (3) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation.

completely that most crop plants suffer from lack of water. Strictly speaking, excessively drained soils are a result of excessive runoff due to steep slopes or low available waterholding capacity due to small amounts of silt, clay, and organic matter in the soil material.

Drill seeding: Planting seed with a drill in relatively narrow rows, generally less than a foot apart.

Ecology: The study of interrelationships of organisms to one another and to their environment.

Ecotype: A locally adapted population of a species which has a distinctive limit of tolerance to environmental factors.

Edaphic factor: A condition or characteristic of the soil (chemical, physical, or biological) which influences organisms.

Edge (wildlife): The transitional zone where one cover type ends and another begins.

Environment: The sum total of all external conditions that may act upon an organism or community to influence its development or existence.

Ephemeral stream: A stream or portion of a stream that flows only in direct response to precipitation, and receives little or no water from springs or no long continued supply from snow or other sources, and its channel is at all times above the water table.

Erosion: (1) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (2) Detachment and movement of soil or rock fragments by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion: Erosion much more rapid than normal, natural, or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophies that expose base surfaces, for example, fires.

Rill erosion: An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently cultivated areas.

Sheet erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Essential element (plant nutrition): A chemical element required for the normal growth and reproduction of plants.

Evergreen: Perennial plants that are never entirely without green foliage.

Exchangeable nutrient: A plant nutrient that is held by the adsorption complex of the soil and is easily exchanged with the anion or cation of neutral salt solutions.

value. (7) Wildlife, plants or objects used by wild animals for nesting, rearing of young, resting, escape from predators, or protection from adverse environmental conditions.

Cover crop: A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.

Creep (soil): Slow mass movement of soil and soil material down relatively steep slopes, primarily under the influence of gravity but facilitated by saturation with water and by alternate freezing and thawing.

Critical area: A severely eroded sediment producing area that requires special management to establish and maintain vegetation in order to stabilize soil conditions.

Cultivar: An assemblage of cultivated plants which is clearly distinguished by its characters (morphological, physiological, cytological, chemical, or others) and which when reproduced (sexually or asexually) retains those distinguishing characters. The terms "cultivar" and "variety" are equivalents.

Cut: Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

Cut-and-fill: Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Debris: The loose material arising from the disintegration of rocks and vegetative material; transportable by streams, ice, or floods.

Deciduous plant: A plant that sheds all its leaves every year at a certain season.

Dispersion, soil: The breaking down of soil aggregates into individual particles, resulting in single-grain structure. Ease of dispersion is an important factor influencing the erodibility of soils. Generally speaking, the more easily dispersed the soil, the more erodible it is.

Diversion dam: A barrier built to divert part or all of the water from a stream into a different course.

Drainage: (1) The removal of excess surface water or ground water from land by means of surface or subsurface drains. (2) Soil characteristics that affect natural drainage.

Drainage, soil: As a natural condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation; for example, in well-drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained, and the roots of ordinary crop plants cannot get enough oxygen; in excessively drained soils, the water is removed so

Chute: A high-velocity, open channel for conveying water to a lower level without erosion.

Clay (soils): (1) A mineral soil separate consisting of particles less than 0.002 mm in equivalent diameter. (2) A soil textural class. (3) (engineering) A fine-grained soil that has a high plasticity index in relation to the liquid limits.

Claypan: A dense, compact layer in the subsoil having a much higher clay content than the overlying material from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry, and plastic and sticky when wet. They usually impede movement of water and air, and the growth of plant roots. See Hardpan.

Clod: A compact, coherent mass of soil ranging in size from 5 to 10 mm to as much as 200 to 250 mm; produced artificially, usually by the activity of man by plowing, digging, etc., especially when these operations are performed on soils that are either too wet or too dry for normal tillage operations.

Colloid: In soil, organic or inorganic matter having very small particle size and a correspondingly large surface area per unit of mass. Most colloidal particles are too small to be seen with the ordinary compound microscope.

Compaction: (1) To unite firmly; the act or process of becoming compact. (2) In geology, the changing of loose sediment into the hard, firm rock. (3) In soil engineering, the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the weight of solid material per cubic foot.

Companion crop: Seeding of a short-life crop with the permanent species to aid in erosion control until the permanent species are established.

Conifer: A tree belonging to the order Coniferae with cones and evergreen leaves of needle shape or "scalelike." The tree is harvested to produce wood known commercially as "softwood."

Contour: (1) An imaginary line on the surface of the earth connecting points of the same elevation. (2) A line drawn on a map connecting points of the same elevation.

Cool-season plant: A plant that makes its major growth during the cool portion of the year, primarily in spring but in some localities in the winter.

Cover: (1) Vegetation or other material providing protection. (2) Fish, a variety of items including undercut banks, trees, roots, and rocks in the water where fish seek necessary proteciton or security. (3) In forestry, low-growing shrubs, vines, and herbaceous plants under the trees. (4) Ground and soils, any vegetation producing a protecting mat on or just above the soil surface. (5) Stream, generally trees, large shrubs, grasses, and forbs that shade and otherwise protect the stream from erosion, temperature elevation, or sloughing of banks. (6) Vegetation, all plants of all sizes and species found on an area, irrespective of whether they have forage or other

Available nutrient: That portion of any element or compound in the soil that readily can be absorbed and assimilated by growing plants. Not to be confused with Exchangeable.

Available water: The portion of water in a soil that can be absorbed by plant roots; usually that water held in the soil against a soil water pressure of up to approximately 15 bars.

Band seeding: Seeding of grasses and legumes in a row 1 to 2 in. directly above a band of fertilizer.

Bedrock: The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feet.

Berm: A shelf or flat area that breaks the continuity of a slope.

Biomass: (1) The total amount of living material in a particular habitat or area. (2) An expression of the total weight of a given population of organisms.

Browse: Twigs or shoots, with or without attached leaves, of shrubs, trees, or woody vines available as forage for domestic and wild browsing animals.

Brush matting: (1) A matting of branches placed on badly eroded land to conserve moisture and reduce erosion while trees or other vegetative covers are being established. (2) A matting of mesh wire and brush used to retard stream bank erosion.

Bulk density: In soils the mass of dry soil per unit bulk volume. The bulk volume is determined before drying to constant weight at 105°C.

Bunchgrass: A grass that does not have rhizomes or stolons and forms a bunch or tuft.

Calcareous soil: Soil containing sufficient free calcium carbonate or magnesium carbonate to effervesce carbon dioxide visibly when treated with cold 0.1 normal hydrochloric acid.

Carrying capacity: (1) In recreation, the amount of use a recreation area can sustain without deterioration of its quality. (2) In wildlife, the maximum number of animals an area can support during a given period of the year.

Cation-exchange capacity (CEC): The sum total of exchangeable cations that a soil can absorb; expressed in milliequivalents per gram or 100 g of soil (or of other exchanges, such as clay).

Channel: A natural stream that conveys water; a ditch or channel excavated for the flow of water.

Channel stabilization: Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

Acid soil: A soil with a preponderance of hydrogen ions and probably of aluminum in proportion to hydroxyl ions. Specifically, soil with a pH value less than 7.0. For most practical purposes, a soil with a pH value less than 6.6. The pH values obtained vary greatly with the method used; consequently, there is no unanimous agreement on what constitutes an acid soil. The term is usually applied to the surface layer or to the root zone unless specified otherwise.

Aeration, soil: The process by which air in the soil is replenished by air from the atmosphere. In a well-aerated soil, the air in the soil is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen. The rate of aeration depends largely on the volume and continuity of pores in the soil.

Aesthetics: The appeal or beauty of objects, animals, plants, scenes, and natural or improved areas to the viewer and his appreciation for such items.

Aggregate: Crushed rock or gravel screened to sizes for use in road surfaces, concrete, or bituminous mixes.

Aggregation, soil: The cementing or binding together of several to many soil particles into a secondary unit, aggregate, or granule. Water-stable aggregates, which will not disintegrate easily, are of special importance to soil structure.

Alkaline soil: A soil that has a pH value greater than 7.0, particularly above 7.3, throughout most or all of the root zone, although the term is commonly applied to only the surface layer or horizon of a soil.

Alluvial land: Areas of unconsolidated alluvium, generally stratified and varying widely in texture, recently deposited by streams, and subject to frequent flooding; a miscellaneous land type.

Alluvium: A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these; unless otherwise noted, alluvium is unconsolidated.

Amendment: Any material, such as lime, gypsum, sawdust, or synethic conditioners, that is worked into the soil to make it more productive. The term is used most commonly for added materials other than fertilizer.

Angle of repose: Angle between the horizontal and the maximum slope that a soil assumes through natural processes.

Annual plant: A plant that completes its life cycle and dies in 1 year or less.

Aquifer: A geologic formation or structure that transmit- ter in sufficient quantity to supply the needs for a water development; usually saturated sands, gravel, fractures, and cavernous and vesicular rock. The term "water-bearing" is sometimes used synonymously with aquifer when a stratum furnished water for a specific use.

APPENDIX A: GLOSSARY

The following list is representative of terms generally used in the various disciplines relating to the restoration of problem soil materials. The definitions have been drawn from several publications; however, the primary source for the majority of terms is the Resource Conservation Glossary (Soil Conservation Society of America 1970).

APPENDIX A: GLOSSARY

Rehabilitation: Implies that the land will be returned to a form and productivity in conformity with a prior land use, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values.

Restoration: Upgrading damaged or recreating destroyed land to restore its biological potential.

Revegetation: Plants or growth that replaces original ground cover following land disturbance.

Revetment: Facing of stone or other material, either permanent or temporary, placed along the edge of a stream to stabilize the bank and to protect it from the erosive action of the stream.

Rhizobia: Bacteria capable of living symbiotically with higher plants, usually legumes, from which they receive their energy, and capable of using atmospheric nitrogen; hence, the term "symbiotic nitrogen-fixing bacteria."

Rhizome: A horizontal underground stem, usually sending out roots and aboveground shoots at the nodes.

Ridge planting: A planting method in which crops are planted on ridges; usually refers to only one seed row planted on each ridge.

Riparian land: Land situated along the bank of a stream or other body of water.

Ripper: Any implement such as a parabolic subsoiler, chisel plow, or ripper used to break apart compacted soil layers below the normal 6-in. plow depth.

Riprap: Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applied to brush or pole mattresses, or brush and stone, or other similar materials used for soil erosion control.

Root zone: The part of the soil that is penetrated or can be penetrated by plant roots.

Runoff (hydraulics): That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground-water runoff, or seepage.

Saline soil: A nonsodic soil containing sufficient soluble salts to impair its productivity but not containing excessive exchangeable sodium. This name was formerly applied to any soil containing sufficient soluble salts to interfere with plant growth, commonly greater than 3000 ppm.

Saltation: Particle movement in water or wind where particles skip or bounce along the stream bed or soil surface.

Sand lens: Lenticular band of sand in distinctly sedimentary banded material.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Seed: The fertilized and ripened ovule of a seed plant that is capable, under suitable conditions, of independently developing into a plant similar to the one that produced it. Types of seed include:

Breeder seed: Seed or vegetative propagating material directly controlled by the originating, or in some cases the sponsoring plant breeder, institution, or firm, and which supplies the initial and recurring increase of foundation seed.

Certified seed: The progeny of foundation or registered seed that is so handled as to maintain satisfactory genetic identity and purity and that has been approved and certified by the certifying agency.

Commercial seed: A term used to designate other than recognized varieties of seed in commercial channels.

Common seed: Noncertified seed. It may be a named variety, but not grown under the certification program.

Dormant seed: An internal condition of the chemistry or stage of development of a viable seed that prevents its germination, although good growing temperatures and moisture are provided.

Firm seed: Dormant seeds, other than hard seeds, that neither germinate nor decay during the prescribed test period under the prescribed conditions. Firm ungerminated seeds may be alive or dead.

Foundation seed: Seed stocks that are so handled as to most nearly maintain specific genetic identify and purity. Production must be carefully supervised by the certifying agency and/or the agricultural experiment station.

Hard seed: A physiological condition of seed in which some seeds do not absorb water or oxygen and germinate when a favorable environment is provided.

Registered seed: The program of foundation seed that is so handled as to maintain satisfactory genetic identity and purity and that has been approved and certified by the certifying agency. This class of seed should be of a quality suitable for production of certified seed.

Seedbed: The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

Seeding, direct (forestry): A method of establishing a stand of trees artificially by sowing seed. In broadcast seeding, seed is sown over the entire area. Partial seeding may be done in strips, furrow rows, trenches, or in seed spots.

Seed purity: The percentage of the desired species in relation to the total quantity of other species, weed seed, and foreign matter.

Seepage: (1) Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring where the water emerges from a localized spot. (2) (percolation) The slow movement of gravitational water through the soil.

Selective herbicide: A pesticide intended to kill specific type plants such as broad-leafed plants only. Similarily, one intended to kill only cereal grasses, but not broad-leafed plants.

Shale: Sedimentary or stratified rock structure generally formed by the consolidation of clay or claylike material.

Shrub: A woody perennial plant differing from a tree by its low stature and by generally producing several basal shoots instead of a single bole.

Slick spots: Barren areas having puddled or crusted, very smooth, nearly impervious surfaces, usually because of high salinity or alkalinity. A miscellaneous area.

Sod: A closely knit ground cover growth, primarily of grasses.

Sodic soil: (1) A soil that contains sufficient sodium to interfere with the growth of most crop plants. (2) A soil in which the exchangeable-sodium percentage is 15 or more. Sodic soils, because of dispersion of the organic matter, have been called black alkali soils; sometimes also called nonsaline-alkali soils.

Soil: (1) The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (2) The unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macroorganisms and microorganisms, and topography, all acting over a period of time and producing a product--soil--that differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. (3) A kind of soil is the collection of soils that are alike in specified combinations of characteristics. Kinds of soil are given names in the system of soil classification. The term "the soil" and "soil" are collective terms used for all soils, equivalent to the word "vegetation" for all plants.

Soil classification: The systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics, subdivisions on the basis of more detailed differences in specific properties.

Soil conditioning: Those essential treatment measures of a physical, chemical, and/or biological nature that are applied to critical areas 1 to 6 months in advance of the establishment of vegetation.

Soil horizon: A layer of soil, approximately parallel to the soil surface, with distinct characteristics produced by soil-forming processes.

Soil material: Any drastically disturbed portion of the earth's surface that could consist of one or more of the soil horizons.

Soil organic matter: The organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil sample passed through a 2-mm sieve.

Soil structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively.

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes; and their productivity under different management systems.

Soil texture: Soil texture class names of soil are based on the relative percentages of sand, silt, and clay.

Spoil: Soil or rock material excavated from a canal, ditch, basin, or similar construction.

Sprigging: The planting of a portion of the stem and root of a plant.

Stolon: A horizontal stem which grows along the surface of the soil and roots at the nodes.

Stratified: Composed of, or arranged in, strata or layers, as stratified alluvium. The term is applied to geological materials. Those layers in soils that are produced by the processes of soil formation are called horizons, while those inherited from parent material are called strata.

Stubble: The basal portion of plants remaining after the top portion has been harvested; also, the portion of the plants, principally grasses, remaining after grazing is completed.

Subsidence: (1) A downward movement of the ground surface caused by solution and collapse of underlying soluble deposits, rearrangements of particles upon removal of coal, or reduction of fluid pressures within an aquifer or petroleum reservoir. (2) The movement of an aerial compound to a lower level; for example, the transport of ozone from the stratosphere to the atmosphere by winds.

Subsoil: The B-horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow.

Although a common term, it cannot be defined accurately. It has been carried over from early days when "soil" was conceived only as the plowed soil and that under as the "subsoil."

Subsoiling: The tillage of subsurface soil, without inversion, for the purpose of breaking up dense layers that restrict water movement and root penetration.

Subwatershed: A watershed subdivision of unspecified size that forms a convenient natural unit. See Watershed.

Supplemental irrigation: Irrigation to ensure or increase crop production in areas where rainfall normally supplies most of the moisture needed.

Surface soil: The uppermost part of the soil ordinarily moved in tillage or its equivalent in uncultivated soils, ranging in depth from about 5 to 8 in. Frequently designated as the plow layer, the Ap layer, or the Ap horizon.

Surface water: All water whose surface is exposed to the atmosphere.

Symbiosis: Two organisms of different species living in close association, one or both of which may benefit and neither is harmed.

Synergism: The simultaneous actions of two or more agencies that, together, have a greater total effect than the sum of their individual effects, for example, the action of certain combinations of toxicants.

Tacking: The process of binding mulch fibers together by the addition of a sprayed chemical compound.

Terrace: An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting surface water.

Terrace types:

Absorptive: A ridge type of terrace used primarily for moisture conservation.

Bench: A terrace approximately on the contour having a steep or vertical drop to the slope below, and having a horizontal or gently sloping part. It is adapted to steeper slopes.

Drainage: A broad channel-type terrace used primarily to conduct water from the area at a low velocity. It is adapted to less absorptive soil and regions of high rainfalls.

Tile, drain: Pipe made of burned clay, concrete, or similar material in short lengths, usually laid with open joints to collect and carry excess water from the soil.

Tillage: The operation of implements through the soil to prepare seedbeds and root beds.

Tolerance: The relative ability of a species to survive a deficiency of an essential growth requirement, such as moisture, light, or nutrient supply, or an overabundance of a site factor such as excessive water, toxic salts, etc.

Topsoil: The unconsolidated earthy material that exists in its natural state above the rock strata and that is or can be made favorable to the growth of desirable vegetation. Usually the A-horizon of soils with developed profiles.

Toxicity: Quality, state, or degree of the harmful effect resulting from alteration of an environment factor.

Tree: A woody perennial plant that reaches a mature height of at least 8 ft and has a well-defined stem and a definite crown shape. There is no clear-cut distinction between trees and shrubs. Some plants, such as the willows, may grow as either trees or shrubs.

Undesirable species: (1) Plant species that are not readily eaten by animals. (2) Species that conflict with or do not contribute to the management objectives.

Vegetation: Plants in general or the sum total of plant life in an area.

Warm-season plant: A plant that completes most of its growth during the warm portion of the year, generally late spring and summer.

Water bar: Any device or structure placed in or upon a haul or access road for the purpose of channeling or diverting the flow of water off the road.

Waterlogged: Saturated with water; soil condition where a high or perched water table is detrimental to plant growth, resulting from overirrigation, seepage, or inadequate drainage; the replacement of most of the soil air by water.

Water management: Application of practices to obtain added benefits from precipitation, water, or water flow in any of a number of areas, such as irrigation, drainage, wildlife and recreation, water supply, watershed management, and water storage in soil for crop production. See <u>Watershed management</u>.

Watershed area: All land and water within the confines of a drainage divide or a water problem area consisting in whole or in part of land needing drainage or irrigation.

Watershed management: Use, regulation, and treatment of water and land resources of a watershed to accomplish stated objectives.

Waterspreading: The application of water to lands for the purpose of increasing the growth of natural vegetation or to store it in the ground for subsequent withdrawal by pumps for irrigation.

Weathering: The erosive effects of the forces of weather on the surfaces of the earth; one of the soil-forming factors.

Weed: An undesired, uncultivated plant.

Xerophyte: A plant capable of surviving periods of prolonged moisture deficiency.

APPENDIX B: DISTRIBUTION OF PROBLEM SOIL MATERIALS BY LAND RESOURCE AREAS

APPENDIX B: DISTRIBUTION OF PROBLEM SOIL MATERIALS BY LAND RESOURCE AREAS

This appendix shows the distribution of soil material groups according to Soil Conservation Service land resource areas and states (Austin 1965). Major land resource areas consist of geographical areas that are characterized by particular patterns of soil (including slope and erosion), climate, water resources, and land use. Figure B-1 designates the land resource areas by numbers. The letters on the figure refer to land resource regions which consist of geographically associated major land resource areas. Table B-1 describes the occurrence of specific problem soil materials and corresponds to the figure.

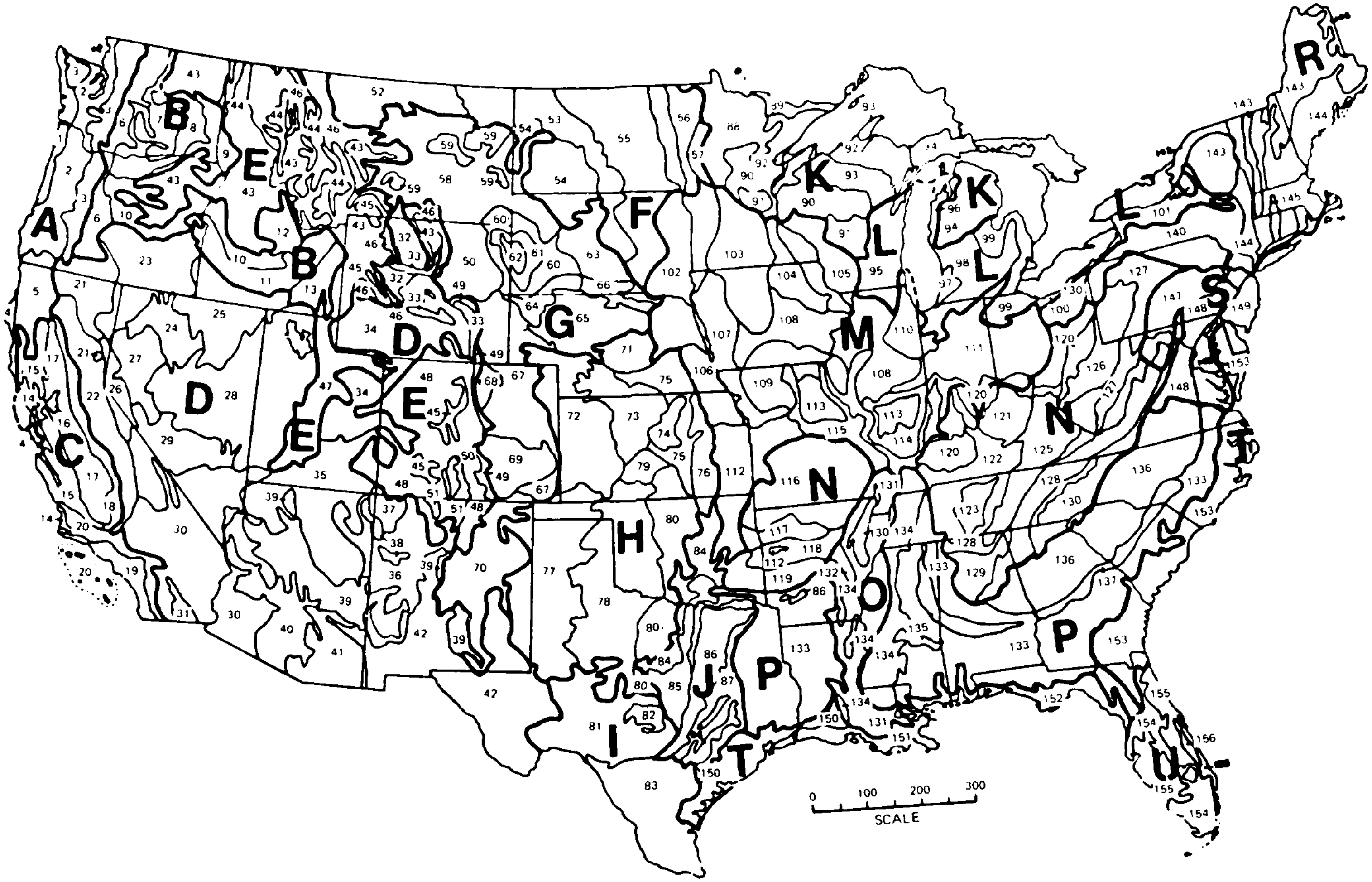

Figure B-1. Land resource regions and major land resource areas of the United States (not including Alaska and Hawaii) (Austin 1965)

Table B-1

States and Land Resource Areas Corresponding to Figure B-1 for the Occurrence of Selected Problem Soils (Austin 1965)

State(s)	Land Resource Area
	Nonpyritic and In Situ Acid Soils
Washington and Oregon	A-2 (up Willamette and Puget Sound Valleys)
Washington and Oregon	A-2 (on western slopes of Olympic and Cascade Mountains)
California	A-4 (Coastal Redwood Belt)
Oregon and Washington	B-6 (on eastern slope of Cascades at higher elevations)
California	D-22 (Sierra Nevada Range humid slopes)
Idaho, Washington, Oregon, Montana, and Wyoming	E-43 (on forested mountain slopes of Northern Rockies)
	E-48 (on forested upper slopes of Southern Rockies)
Texas and Oklahoma	J-84 (in the humid east Texas)
Texas	J-87 (in east Texas claypan area)
Minnesota and Wisconsin	K-90 (in loessial till)
Wisconsin and Minnesota	K-91 (in sandy outwash)
Wisconsin and Michigan	K-93 (in loessial till)
Michigan	K-94 (in sandy glacial drift)
Wisconsin and Illinois	L-95 (in medium- to fine-textured glacial drift)
Michigan	L-96 (in coarse glacial drift)
Michigan	L-97 (in coarse glacial drift)
Michigan and Indiana	L-98 (in medium- to coarse-textured acid glacial drift)
Michigan and Ohio	L-99 (in fine- and medium-textured materials)
Ohio, Pennsylvania, and New York	L-100 (in western portions)
New York	L-101 (derived from calcareous glacial drift)
Minnesota and Iowa	M-103 (in leached glacial till)

(Continued)

(Sheet 1 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Nonpyritic and In Situ Acid Soils (Continued)	
Minnesota and Iowa	M-104 (in leached till)
Wisconsin, Iowa, Minnesota, and Illinois	M-105 (in loessial mantle)
Iowa and Illinois	M-108 (on steep slopes of valley sides)
Illinois and Indiana	M-110 (on glacial till)
Indiana, Ohio, Michigan, and Illinois	M-111 (on leached till)
Missouri and Illinois	M-113 (on steep valley sides)
Illinois, Indiana, and Ohio	M-114 (on sloping uplands)
Missouri, Illinois, and Indiana	M-115 (in loess and on ridgetops)
Missouri, Arkansas, and Oklahoma	N-116 (leached limestones)
Missouri, Arkansas, and Oklahoma	N-117 (on moderately steep slopes of Boston Mountains)
Arkansas and Oklahoma	N118 (on hilly to steep ridges)
Arkansas and Oklahoma	N119 (on gentle slopes of ridgetops and foot slopes of Ouachita Mountains)
Kentucky and Indiana	N-120 (on smooth flats and low hills)
Kentucky, Indiana, and Ohio	N-121 (on rolling to hilly uplands)
Kentucky, Tennessee, Indiana, and Alabama	N-122 (in loess)
Tennessee	N-123 (on dissected outer borders of area)
Ohio	N-124 (on rolling ridgetops)
Kentucky, Tennessee, and West Virginia	N-125 (on rolling plateaus and on smooth plateau tops and on foot slopes of Cumberland Mountains)
West Virginia, Pennsylvania, and Ohio	N-126 (on steep slopes and on gently sloping to rolling ridgetops)
Pennsylvania, West Virginia, and Maryland	N-127 (on level to rolling areas)
Virginia, West Virginia, Tennessee, Georgia, and Alabama	N-128 (in valleys)

(Continued)

(Sheet 2 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Nonpyritic and In Situ Acid Soils (Continued)	
Alabama	N-129 (on smooth plateau top of Sand Mountain)
North Carolina, Virginia, Georgia, Tennessee, South Carolina, and Maryland	N-130 (on mountain sides)
Arkansas, Louisiana, Missouri, and Tennessee	O-131 (on older Mississippi River terraces)
Arkansas	O-132 (eastern Arkansas prairies)
Georgia, Alabama, Mississippi, Louisiana, Texas, Arkansas, Tennessee, North Carolina, South Carolina, Virginia, and Florida	P-133 (coastal plain)
Mississippi, Tennessee, and Kentucky	P-134 (in thick loess on gently rolling to hilly uplands and terraces)
Alabama and Mississippi	P-135 (at highest elevations of blackland prairies)
Virginia, North Carolina, South Carolina, Georgia, and Alabama	P-136 (southern Piedmont)
Georgia, South Carolina, and North Carolina	P-137 (in Carolina and Georgia sand hills)
Florida	P-138 (in southern Florida)
Ohio	R-139 (eastern Ohio)
New York	R-141 (from acid, glacial till)
New York and Vermont	R-142 (on higher till plains and outwash plains)
New York, Maine, New Hampshire, Vermont, and Massachusetts	R-143 (in glacial till)
Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, and New Jersey	R-144 (on higher hills and sandy glacial outwash)
Connecticut and Massachusetts	R-145 (in glacio-lacustrine or marine sediments)
Maine	R-146 (from glacial till and outwash)

(Continued)

(Sheet 3 of 9)

Table C-1 (Continued)

Soil Material	Analysis	Remarks	Procedural Reference
Poorly drained*	Water table	Depth, type, and variation. Depth to ground water is most common index of adequacy of drainage. More measurements needed at sites where abrupt changes in slope of water table occur	US Salinity Lab. Staff (1954)
	Subsurface stratigraphy	Texture, position, and extent of subsurface soil materials	US Salinity Lab. Staff (1954)
	Water transmission properties of soil	Hydraulic conductivity both horizontally and vertically. Determined in part by particle-size distribution (soil texture) and soil structure Soils are extremely variable due to heterogeneous nature	Boersma (1965)
	Soil compaction levels	Analyzed by laboratory bulk density and field penetrometer soil strength measurements	Davidson (1965); Felt (1965)

(Continued)

* Results of various tests need to be considered collectively to determine if poor internal drainage is a problem.

(Sheet 3 of 4)

Table C-1 (Continued)

Soil Material	Analysis	Remarks	Procedural Reference
Saline and sodic	Electrical conductivity	For measuring soluble salt content in millimhos per centimetre. Automatically allows for the salt-dilution effect that occurs in fine-textured soils. Disturbed or excavated saline soil materials that contain large amounts of sand and coarse fragments of regolith may provide false indications of salinity or lack of it	US Salinity Lab. Staff (1954); Berg (1978); Rhodes (1982) Berg (1978)
	Exchange cation percentages	For evaluating the extent of exchangeable sodium in highly alkaline soil materials. Estimates the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP) through soil tests and a nomogram	US Salinity Lab. Staff (1954). Use flame emission for Na, atomic adsorption for Ca, Mg, and K. Rhodes (1982)
Excessively drained	Particle size	Results of various tests need to be considered collectively to determine if excessive internal drainage is a problem	US Salinity Lab. Staff (1954); Day (1965); Sandoval and Power (1982)
	Silt plus clay content	Hydrometer test for silt and clay	Day (1965)
	Available nutrients	Tests for available N, P, K, Ca, Mg, and other nutrients	Sandoval and Power (1977)

(Continued)

(Sheets 2 of 4)

Table C-1

Chemical and Physical Analyses of Problem Soil Materials

Soil Material	Analysis	Remarks	Procedural Reference
Acid	Standard water pH	To determine active acidity. Used where soluble salt levels not unduly high	McLean (1982)
	Buffer pH	To determine exchangeable acidity. Used where soluble salt levels suspected as being high	Follow procedure used by the respective state soil
	Lime requirement	To determine the amount of lime required to raise soil pH to some level	Follow procedure used by the respective state soil testing laboratory
Acid-sulfate*	Potential acidity	Used on samples known or suspected of having high sulfide levels	Barnhisel and Bertsch (1982) Appendix H
	Acid-base accounting*	To predict extreme acidity of disturbed materials and likely associated concentrations of toxic metals	Sobek et al. (1976); Smith and Sobek (1976)
		Considers total and potential pH plus neutralization potential of basic materials	
	Exchangeable aluminum	To predict aluminum levels adsorbed to soil or clay minerals under extremely acid conditions. It is advisable to base lime requirement estimates on exchangeable aluminum as well as pH	Barnhisel and Bertsch (1982)

(Continued)

* Opinion varies as to the most acceptable method for measuring active acidity and lime requirement. A detailed discussion of acid-sulfate soils is presented in Appendix H.

(Sheet 1 of 4)

- Cation exchange capacity (Jackson 1958; Page, Miller, and Keeney 1982, pages 149-157).
- Particle-size distribution (Patrick 1958; Day, 1965).
- Salinity (Page, Miller, and Keeney 1982, pages 167-178).
- Available nutrients (Southern Cooperative Series 1974, or State Soil Test Laboratory Procedure).

These soil tests provide the basic information for standard soil conditioning and fertilizer requirements whether or not problem soil materials are present. The tests can also indicate the possible presence of more severe problem soil materials. If this is the case, more specific soil tests can then be conducted to identify the problem soil materials.

5. Figure C-1 summarizes the various chemical and physical analyses that should be considered under a two-phase testing approach.

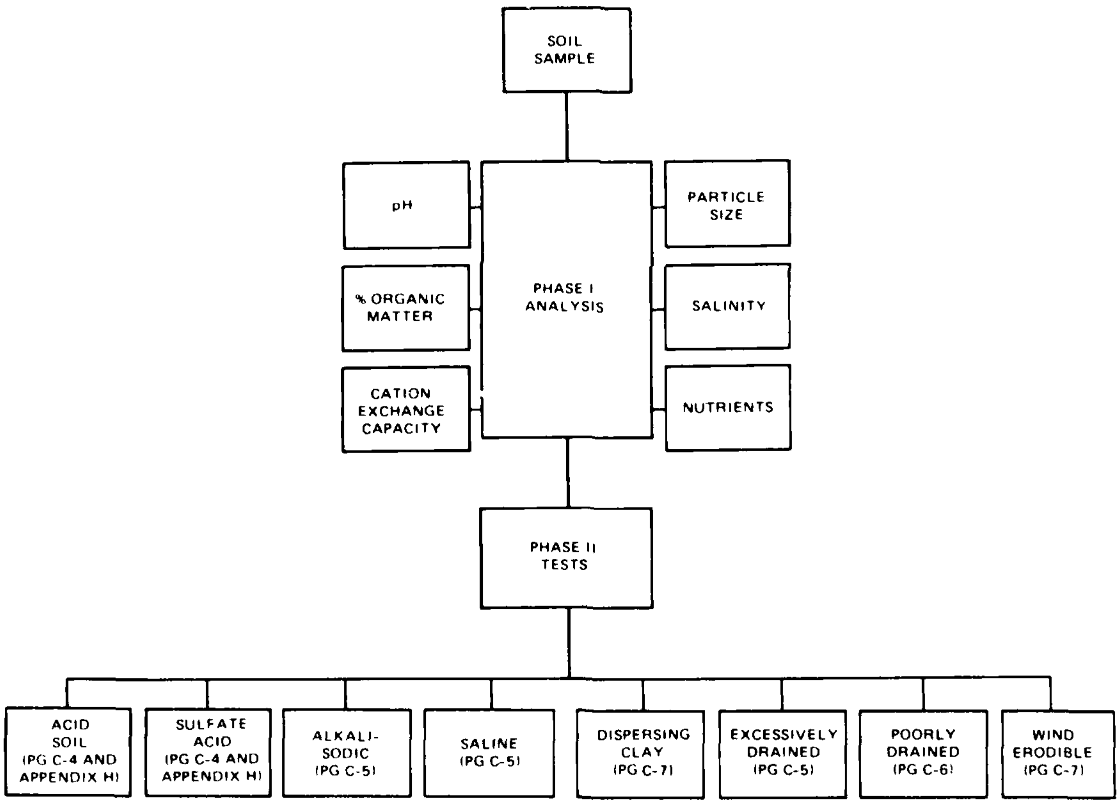

Figure C-1. Summary and flow diagram of soil tests recommended for a collected soil sample (page numbers refer to Table C-1)

uniform cores or slices of equal volume to the depth desired. The tool should be easy to clean and adaptable to dry, sandy soil as well as to relatively moist, clayey soil. Shovels, trowels, soil tubes, and augers are commonly used. When sampling for micro-nutrients or trace metals, tools containing the metals of interest should not be used. The depth of sampling depends on the analyses to be conducted, the vegetation to be grown, and previous knowledge of the soil. If a soil survey of the area has been conducted, sampling of the subsoil probably is not necessary for macronutrient studies. Sampling of the soil to a depth of at least 5 ft (1.5 m) is necessary to determine textural discontinuities or compacted layers that affect water penetration and root distribution....

d. Preserve and transport the samples to the laboratory. Samples should be handled in a manner that will minimize any changes in properties. Samples for analysis of soil constituents subject to rapid changes, such as carbohydrates and proteins, should be frozen or dried rapidly at low temperatures. Waterproof bags or containers should be used for salinity or boron samples to avoid salt absorption from moist samples. Suspected pyritic samples should be stored in airtight containers (not plastic bags) for transport to the laboratory. Any necessary mixing, splitting, and subdividing of the sample for individual tests should be done in the laboratory.

3. According to Barnhisel (1976b) the number of subsamples required for a composite sample of surface mined soils "...will depend on the uniformity of the soils, and to some extent on the revegetation objectives." This will also influence the number of composite samples needed to "represent the area" (Barnhisel 1976b). After the composite samples have been collected, place "on clean kraft papers in a dust-free area to dry them. Do not use artificial heat to dry samples....After air-drying, place a portion of each sample into its own small paper box...." (Barnhisel 1976b). Suspected pyritic samples should be freeze dried, ground to a fine powder, and stored in an airtight container. Other sampling guidelines that are valid for soil materials found at Corps of Engineers project sites have been published by the US Department of Agriculture (USDA) Soil Survey Staff (1972); USDA, SCS (1976); and the Southern Cooperative States (Southern Cooperative Series 1974).

4. Several Phase I soil tests should be conducted on all soil samples:

- Standard water pH and/or buffer pH (Page, Miller, and Keeney 1982, pages 199-223).
- Percent organic matter (Page, Miller, and Keeney 1982 pages 539-577).

APPENDIX C: METHODOLOGY FOR ONSITE SURVEYS

1. This appendix describes a recommended two-phase testing approach and the methodologies to be used for onsite surveys. This methodology begins with soil sampling procedures and describe the various tests that could be conducted and what the test results indicate.

Determination of Soil Properties on Problem Soil Areas

2. Because there is no standard soil sampling procedure, the following procedures, quoted verbatim from US Environmental Protection Agency Process Design Manual for Land Treatment (1977),* are recommended for use:

> a. Subdivide the area into homogeneous units. The criteria for homogeneity are somewhat subjective and may include visual differences in the soil or vegetative known differences in past management, or other factors. Uniform areas should be subdivided further into sampling units ranging in size from 5 to 40 acres (2 to 8 ha), depending on the area of uniformity.
>
> b. Establish a pattern such as a grid to denote sampling points. In general, samples should be composites of several subsamples from the area to minimize the influence of micro-variations in soil properties....However, compositing is not advisable when sampling for salinity testing, because there may be large variations in soluble salts over very small areas. The number of subsamples necessary to represent the sample area adequately varies with the degree of accuracy desired, the test to be conducted, the type of soil, and previous management. No universally accepted number has been defined, but a minimum of 10, and preferably 20, subsamples has been suggested as a guideline. A grid pattern should be used if sites are bare or if the status of the entire area is to be represented. If the identification of problem areas is the objective of the testing, and vegetation is present, the distribution of vegetation and its appearance may indicate affected areas and thus serve as a guide in selecting sampling sites. When sampling affected areas, adjacent unaffected areas should be sampled for comparison. These kinds of data will aid in defining the problem in the affected area. Nonrepresentative spots should be avoided when sampling.
>
> c. Collect samples of the soil. Samples should be collected with a tool that will take a small enough equal volume of soil from each sampling site so that the composite sample will be of an appropriate size to process. A composite sample volume of 1 to 2 pt (0.5 to 1 L) is normally adequate. The most important consideration in selecting a sampling tool is that it provide

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* References cited in this appendix refer to those in Section VII.

APPENDIX C: METHODOLOGY FOR ONSITE SURVEYS

Table B-1 (Concluded)

State(s)	Land Resource Area
Excessively Drained Soils (Concluded)	
New Jersey, Maryland, Virginia, New York, Massachusetts, and Delaware	S-149 (deep sands of the northern Coastal Plain)
Florida	U-154 (acid and phosphatic sands of the South Central Florida Ridge)

(Sheet 9 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
	Excessively Drained Soils (Continued)
South Dakota and Nebraska	G-64 (in deep sands and tablelands)
Nebraska	G-65 (Nebraska Sand Hills, 14,000 square miles)
South Dakota and Nebraska	G-66 (sloping sandy areas of eroded tablelands)
Wyoming, Colorado, and Nebraska	G-67 (deep sands on hilly topography of Central High Plains)
Colorado	G-68 (deposits of windblown sands and silts on steep slopes)
Texas, Oklahoma, and Kansas	H-78 (deep sandy materials in Central Rolling Red Plains)
Kansas	H-79 (dunelike topography in Great Bend Sand Plains)
Texas	H-80 (deep sands in Central Rolling Red Prairies)
Texas	I-83 (sands of the Rio Grande Plain along gulf coast)
Wisconsin and Minnesota	K-91 (sandy glacial outwash)
Wisconsin and Michigan	K-93 (deep sands in glacial drift plains of Great Lakes)
Michigan	K-94 (deep sands of the northern Michigan glacial drift plain)
Michigan	L-96 (deep, acid sands of western Michigan)
Michigan	L-97 (coarse deep sands of south-western Michigan)
South Dakota, Minnesota, Nebraska, and Iowa	M-102 (deep sands on sloping areas)
Georgia, Alabama, Mississippi, Louisiana, Texas, Arkansas, North Carolina, South Carolina, Virginia, and Florida	P-133 (Southern Coastal Plain sands)
Georgia, South Carolina, and North Carolina	P-137 (deep sands and gravels of Carolina and Georgia Sands Hills)
Florida	P-138 (deep sands of North Central Florida Ridge)

(Continued)

(Sheet 8 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Soils with Calcareous Subsoil Materials (Vertisols) (Concluded)	
Texas	T-81 (in valleys and on nearly level uplands)
Texas	T-83 (in calcareous clays in northern and central areas)
Texas and Oklahoma	J-85 (soft limestones)
	J-86 (on gently sloping uplands and underlain by marls and highly calcareous clays)
Excessively Drained Soils	
Oregon and Washington	B-6 (in pumice and glacial till)
Washington and Oregon	B-7 (on sandy terraces)
California	C-17 (deep, dry sands)
California	D-22 (in granitic materials)
Nevada	D-27 (on moderate slopes)
Nevada and California	D-29 (wind-deposited sands of the southern Nevada Basin)
New Mexico and Arizona	D-36 (in deep sands)
New Mexico	D-37 (windblown sands on alluvial fans)
New Mexico, Texas, and Arizona	D-42 (in deep sands of desertic basins and plains)
Montana and Idaho	E-44 (in deep unconsolidated materials)
Colorado and Wyoming	E-49 (windblown sands)
Colorado	E-50 (in deep sands of San Luis Valley)
North Dakota, Montana, and South Dakota	F-53 (in glacial till)
North Dakota and South Dakota	F-55 (in glacial till)
North Dakota and Minnesota	F-56 (old beach ridges and sand dunes in Red River Valley of the North)
Montana	G-59 (in small areas of glacial till in eastern Montana)

(Continued)

(Sheet 7 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Soils with Calcareous Subsoil Materials (Mollisols, Aridisols) (Concluded)	
Arizona	D-40 (in higher calcareous materials)
Arizona	D-41 (in higher calcareous materials)
New Mexico, Texas, and Arizona	D-42 (in highly calcareous materials)
Colorado	G-69 (sand total extent)
Texas, New Mexico, Oklahoma, and Kansas	H-77 (dominant on more sloping parts and in shallow valleys)
Texas, Oklahoma, and Kansas	H-78 (in areas with strong caliche materials)
Texas	H-81 (on better drained level to gentle slopes)
Texas	H-83 (in sandy and silty old alluvium on stream terraces and deltas in south and west Texas)
Soils with Calcareous Subsoil Materials (Vertisols)	
California	C-14 (in fine-textured sediments of valleys)
California	C-15 (in clayey materials)
California	C-19 (in fine-textured materials)
California and Oregon	D-21 (on uplands and in basins)
Nevada, Oregon, and California	D-23 (in dry lake basins)
Wyoming	D-33 (in areas underlain by basic rocks)
North Dakota and Minnesota	F-56 (in medium- to fine-textured lacustrine sediments)
Kansas	H-74 (on gentle slopes of sandstone uplands)
Nebraska and Kansas	H-75 (on nearly level and gently sloping uplands)
Kansas and Oklahoma	H-76 (in more deeply weathered clays and limestones of nearly level uplands)

(Continued)

(Sheet 6 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Sodic and Saline Soils (Concluded)	
Nevada	D-24 (in basins)
Nevada, Oregon, and Idaho	D-25 (in lower basins)
Nevada	D-27 (in lower basins)
Utah, Nevada, and Idaho	D-28 (in alkali basins)
California, Arizona, Nevada, and Utah	D-30 (in low basins)
Wyoming and Montana	D-32 (in alkaline clay shales)
Wyoming, Colorado, and Utah	D-34 (in small basins)
Montana and Idaho	E-44 (in deep unconsolidated parent materials)
Montana and Wyoming	E-46 (in small basins)
Montana	F-52 (on gently sloping uplands)
North Dakota, Montana, and South Dakota (Glaciated Plain)	F-53 (on gently sloping uplands)
North Dakota and South Dakota (Glaciated Plain)	F-54 (on very gently undulating plains and terraces)
Montana, Wyoming, South Dakota, and North Dakota	G-58 (on very gentle slopes)
Montana	G-59 (on very gentle slopes)
South Dakota, Wyoming, and Montana	G-60 (level to gentle slopes)
Nebraska only	H-71 (nearly level area or terraces)
South Dakota and Nebraska	M-102 (in depressions)
Soils with Calcareous Subsoil Materials (Mollisols, Aridisols)	
Idaho and Oregon	B-11 (on loess-capped lava plains)
Idaho	B-12 (on gently sloping valley fans)
Utah, Nevada, and Idaho	D-28 (on old alluvial fans)
Nevada and California	D-29 (in coarser alluvial deposits)
California, Arizona, Nevada, and Utah	D-30 (on older alluvial fans)
Arizona	D-38 (on higher fans, terraces, foothills)

(Continued)

(Sheet 5 of 9)

Table B-1 (Continued)

State(s)	Land Resource Area
Nonpyritic and In Situ Acid Soils (Concluded)	
Pennsylvania, Maryland, West Virginia, and Virginia	S-147 (northern Appalachian ridges and valleys)
Pennsylvania, Maryland, Virginia, New Jersey, and Delaware	S-148 (northern Piedmont)
New Jersey, Maryland, Virginia, New York, Massachusetts, and Delaware	S-149 (northern coastal plain)
Florida, Alabama, and Mississippi	T-152 (Gulf Coast Flatwoods on better drained lands)
Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida	T-153 (Atlantic Coast Flatwoods drained areas)
Florida	U-154 (in phosphatic parent materials of South-Central Florida Ridge)
Saline Soils	
Idaho	B-12 (lacustrine deposits and floodplains)
Nevada	D-24 (in basins)
Nevada and California	D-26 (older fans and terraces)
Nevada	D-27 (in lower parts of basins)
Utah, Nevada, and Idaho	D-28 (in salt basins)
North Dakota and South Dakota	F-55 (northeastern Dakotas)
North Dakota and Minnesota	F-56 (on level slopes of sandy deltas and lake plains)
Minnesota	F-57 (in silty deposits)
Sodic and Saline Soils (Alfisols, Aridisols, Mollisols*)	
California	C-17 (dry areas)
Nevada, Oregon, and California	D-23 (in dry lake basins)

(Continued)

* As a matter of convenience, the calcareous materials are listed under the separate headings according to terminology in Agriculture Handbook No. 436, Soil Taxonomy, (USDA 1975).

(Sheet 4 of 9)

Table C-1 (Concluded)

Soil Material	Analysis	Remarks	Procedural Reference
Dispersive* clays	SCS pinhole test	Appears to be best test to date. Models erosional performance of clay soil materials subjected to the erosive action of a concentrated stream of water	Lewis and Schmidt (1976)
	Dissolved salts in pore water		Flanagan and Holmgren (1976)
	SCS dispersion test	Tests soil samples on their natural moisture content (undried). Distilled water is used	Decker and Dunnigan (1976)
	Soil aggregate test**	Also called crumb test	Holmgren and Flanagan (1976)
Wind erodible	Sieve analysis	To determine if soil materials are susceptible to wind soil loss, 20-mesh sieve is used	Kemper (1965)
	Wind erosion potential	Erosion equation to determine potential in tons per acre per year	Kemper and Chepil (1965)

* Results of various tests need to be considered collectively to determine if poor internal drainage is a problem.

** At the present level of understanding of dispersive clay materials, it is imperative that all four tests be made on a large number of samples. Atterberg limits, particle-size distribution, and visual classification schemes are unacceptable because of their proven inadequacy.

(Sheet 4 of 4)

6. State soil testing laboratories or soils research departments should be the first choices for laboratory analyses for the following reasons:

- Their tests have been calibrated for local soil conditions with extensive field testing to back up recommendations.
- Their interpretations are most likely to be valid.
- Their services are usually provided free or at a lower cost than commercial laboratories.

A second choice for laboratory analyses should be Corps of Engineers laboratories. Commercial laboratories should be recommended only when state facilities are not available. Commercial laboratory results are excellent but they tend to apply the same interpretation of the results from different areas and pay less attention to changes in clay mineralogy.

Vegetation Surveys

7. An offsite vegetation survey is important in that it can provide baseline information on native indicator plant species and plant succession on hostile conditions comparable to those found at the project site. Such a survey also can provide an indication of the wildlife species that actually use these habitats. Of equal importance is the correlation between soil factors such as moisture imbalance and texture and plant species that occur at different levels of stress, slope exposure, and elevation comparable to those at the project site.*

8. Interrelationships of vegetation and predominat varieties present offsite should be studied along with quantitative measurements of height, area covered, and density (Milner and Hughes 1968; Cook and Bonham 1977). Unique species of vegetation should be noted as well as their particular role in the local ecosystem. With the current emphasis on replanting native species of vegetation or acceptable and proven substitutes, a consideration of these should be made at this stage. Required vegetative analyses can be performed using sampling and analytical techniques recommended by local range and forestry experts.

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* Contact USDA Forest Services, Rocky Mountain Forest and Range Experimental Station, Albuquerque, New Mexico, for a vegetation classification system developed for ecosystems in the southwestern United States.

9. An analysis of the offsite and onsite vegetation will aid in the formulation of a site restoration plan designed to provide a suitable, permanent, and diverse vegetative cover capable of:

- Feeding and withstanding grazing pressure from a quantity and mixture of wildlife and domestic livestock at least comparable to that which the land could have sustained prior to disturbance.
- Regeneration under the natural conditions prevailing on the site including climatic abnormalities such as drought, heavy snow, and strong winds.
- Preventing soil erosion by water and wind.

10. Vegetative site analysis plans should be discussed with local range and forestry experts prior to and during the field work. All methods of analysis and testing procedures should be described in detail. The offsite areas should have the following characteristics:

- They should have vegetative species and community types representative of the area to be restored.
- They should have soil and topographic conditions similar to the area to be restored.
- They should be protected from uncontrolled grazing by domestic livestock and wildlife.
- They should be protected from a variety of other disturbances associated with the onsite and offsite activities.

Comparative analysis between revegetated areas of the project site and control (or reference) areas can be made to determine the success of the stabilization and revegetation efforts. Preconstruction vegetative inventories may be available to allow comparisons of that data with other similar onsite and offsite data.

11. It is important to measure the presence of all wildlife species in the project area (or watershed) and their role in the ecological community and food chain. Threatened and endangered species have been the primary focus of fish and wildlife population inventories because of the legal implications of their disruption. The Endangered Species Act can have significant effects on planned restoration activites in watersheds. Transects, plots, observation areas, etc., used for the vegetative studies should not only be compared with soils data but can also be used for wildlife studies (States et al. 1978).

Topographic Evaluation

12. Topography of the project restoration site and the watershed or subwatershed of which it is a part should be studied and displayed in detail on a base map. This map should include boundaries of the watershed or subwatershed and major topographic features such as peaks, lakes, streams, and shorelines. The relationship of the restoration site to adjacent land morphology and stream classes needs to be identified also (Strahler 1964; Wertz and Arnold 1972; Platts 1974). Topographic maps can be created in any of several ways. The US Geological Survey or Army Map Service has topographic quadrangle sheets on scales of 1:62,500, 1:31,680, or 1:24,000. If the project is of sufficient magnitude to justify the high costs, a far more accurate method of making topographic maps is to fly an original aerial survey and, with the aid of ground surveyed control points, create the map.

13. The topographic map is used to determine slope aspect, which is important to the revegetation effort because south-facing slopes are subject to more solar radiation and, therefore, more evaporation of surface moisture than north-facing slopes. Site elevation variations are also determined. Special topographic features, such as cliffs or depressions, and microtopographic conditions must frequently be analyzed by more detailed field techniques. Microtopography is the small-scale relief of the ground surface and it is critical to regegetation because the conservation of soil moisture and protection of seeds and seedlings is aided by the presence of small depressions in graded surfaces which would not be depicted on the topographic map. Topography is also an important consideration in wildlife habitat planning.

14. The scenic quality of the area can depend on topography and attempts must be made to mitigate scenic impacts due to past earth-moving activities and to restore the ground surface to an acceptable visual quality. Since the shape of the earth's surface greatly reflects the subsurface geology (in fact geology controls the large-scale topography of an area) and also the hydrology (both surface and ground-water systems), the topographic study will shed some light on these site characteristics. An example would be that the ground- water table generally follows the surface topography, rising with hills and dropping in valleys.

Climatic Evaluation

15. Climatological data which are representative of the restoration site should include the following as a minimum requirement:

- Average seasonal precipitation.
- Average direction and velocity of prevailing winds.
- Seasonal temperature ranges and growing seasons.
- Evapotranspiration.

16. It is important to determine the annual amount of precipitation. In the Western United States much of the total annual precipitation is in the form of snow. Snow provides moisture for soils and plants when it melts in the spring. Runoff from melting snow can be heavy and could cause erosion. When the snow does melt in the spring, much of it may evaporate directly into the atmosphere without converting to the liquid state. This process is called sublimation and the ratio of how much available water can be expected from the total snowfall can be estimated by several methods (Thornthwaite 1948; Blaney and Criddle 1950; Penman 1956).

17. Snowfall data can be obtained from records of previous weather conditions and from site measurements. One winter's measurement of snowfall, however, may not provide statistically acceptable data. Weather records are kept by the National Weather Service, National Oceanic and Atmospheric Administration (NOAA), and state and local agencies. Neighboring mine sites are also sources of climatological data. Historical weather records of the area should be referenced.

18. Water loss is an important factor for revegetation. The combined loss of water to the atmosphere by evaporation and plant transpiration or evapotranspiration is crucial in the arid West because the water loss rates exceed precipitation rates. Water loss from evaporation of standing bodies of water also occurs where the evaporation rate exceeds precipitation. Typically, evaporation rates for particular areas in the West are recorded in numerous locations by the National Weather Service. The evaporation rate from standing bodies of water is measured in inches or centimetres per year and water losses of 20 in./year are not uncommon.

19. Calculation of evapotranspiration rates under arid and semiarid climatic conditions can be made by any of several methods. Some of the best and most commonly used estimation methods are those of Thornthwaite, Blaney

and Criddle, and Penman, cited above. If extensive meteorological data are not available and the climate is semiarid, with well-defined cool-hot and wet-dry seasons, the Thornthwaite and Blaney-Criddle methods are best suited (Thornthwaite 1948; Blaney and Criddle 1950). Also, the equations predict evapotranspiration best where single plant species exist and where ground water is available to plant roots in unlimited quantities.

Hydrologic Evaluation

20. The hydrologic characteristics of both the surface and ground-water supply at the restoration site must be mapped and described in detail. Perhaps the most useful publications for subsurface hydrological investigations are the US Geological Survey (USGS) Water Supply Papers, which report on the geology, hydrology (including aquifer characteristics and properties), water quality, and utilization of water resources for a particular area, basin, or region. The USGS maintains offices in almost all of the states and can often furnish open file data on request. These offices usually have lists which identify all USGS published reports and geologic maps for areas within the state, as well as the reference libraries within that state where reports or data may be consulted.

21. State geological or water surveys can often provide some of the best local information on water levels, water quality, and location of wells. Many states maintain an inventory of wells drilled in the state. Other state groups such as the pollution control agencies, offices of environmental quality, or departments of natural resources can provide information on local water quality. Agencies such as flood control districts and soil conservation districts may maintain records on selected wells. This information may or may not require field verification. It should be noted that static ground-water inventories can be extremely spotty because, even though required by law in many states, water well drillers do not always file the required reports on well location, depth, and rock strata penetrated, nor does the information always get reported accurately. Seepage and, possibly, a significant depression in the local ground-water level will occur when the water table is intercepted during excavation. Where saline-forming materials are present, contamination of ground water can be a problem following backfilling.

22. In some cases, adequate information cannot be obtained from published sources. If this occurs, data from the field must be collected. Piezometers and observation wells are used in ground-water studies for measuring water levels, collecting water samples, and for permeability testing. The term "piezometer" refers to one of the many types of instruments which are used to monitor water levels in low permeability materials (Boersma 1965; US Salinity Laboratory Staff 1954). An observation well is a cased and/or screened borehole generally from 0.75 to 4 in. in diameter, which is used to monitor ground-water level and quality (US Salinity Laboratory Staff 1954). Level measurements and samples are normally collected manually on a periodic basis. An automatic level recorder can be installed to collect continuous level readings. The observation wells can also be pumped or "slug tested" (falling head permeability test) to determine aquifer characteristics.

23. Surface water information should include the names of the watersheds involved; the location of all surface water bodies, such as streams, lakes, ponds, and springs; the location of any water discharge into the surface water supply; and descriptions of surface drainages sufficient to identify seasonal variations in water quality and quantity (i.e., perennial or intermittent stream) on the proposed restoration site and surrounding area. Surface water information should also include:

- Minimum, maximum, and average discharge conditions which can be used to identify critical low flow and peak discharge rates of streams.
- Water quality data sufficient to identify the characteristics of surface waters in, discharging into, or which will receive flow from surface or ground water from affected areas.
- Total dissolved solids in milligrams per litre.
- Total suspended solids in milligrams per litre.
- Acidity.
- pH in standard units.
- Total and dissolved iron in milligrams per litre.
- Total manganese in milligrams per litre.

24. Water quality testing and sampling techniques are detailed in two US Environmental Protection Agency reports (USEPA 1979a and 1979b). These should be consulted prior to beginning any water analysis program.

25. Water supply data shall also include information sufficient to identify the extent to which the proposed CWP restoration activities may

contaminate, diminish, or interrupt surface or water supplies in the area which are used for domestic, agricultural, industrial, or other legitimate uses. If pollution or a decrease in the quantity of available water is anticipated, then alternative sources of water supply must be identified. Such alternative water sources will be developed to replace the depleted or polluted existing sources.

Visual Resources

26. The inventory and evaluation of the visual resource of a CWP/DOA site shall be treated as an essential part of, and receive equal consideration with, the other resources of the land. Aesthetics are an especially important consideration in areas of high visibility by the public. Engineering competence is and will be judged in part by the landscape architectural plans and designs. The amount of detail necessary for the visual resource inventory will depend on the land unit's complexity, the scale of the land management or project plan(s), and the physical attributes of proposed management activities (USDA, Forest Service 1974a, 1975a; US Department of the Interior 1975).

27. A successful visual inventory requires an understanding of the basic elements of the landform and surface pattern. Surface pattern includes waveforms, vegetation, rockforms, and/or structures.

28. It is essential to identify the level of concern held by residents and visitors in an area. Social surveys, photographic preference testing, personal interviews, or "best professional judgment" supply this information. It is also important to determine the location and spatial distribution of the various quantities and sensitivities of groups of people.

29. A variety of methods exist to identify visibility from human locations. Both manual and computer-aided methods can be used. Computers have made it possible to perform very detailed analyses on both large and small study areas (American Society of Landscape Architects 1978).

30. Information collected during the inventory shall provide all the necessary input for a visual analysis by the interdisciplinary team. The basic objective of the analysis is to develop criteria on which proper decisions can be made for the management of the "seen" aspects of the landform and the activities occurring on its surface.

31. Several processes for visual analysis have been developed in recent years--some for urban areas and some for natural areas. Methodology for visual analysis techniques is detailed in National Forest Landscape Management of the US Department of Agriculture, Forest Service (April 1974, July 1975, March 1977, and May 1977).

APPENDIX D: SOIL STABILIZATION MEASURES

APPENDIX D: SOIL STABILIZATION MEASURES

CHECK DAMS

1. A check dam (Figure D-1) is a low-head structure or barrier constructed of durable materials such as stone or logs that are placed across a natural or man-made channel. It is used to stabilize the grade or to control head cutting in natural or artificial channels. Check dams are used to reduce or prevent excessive erosion by reduction of velocities in watercourses or by providing partially lined channel sections or structures that can withstand high flow velocities. The lower velocity reduces the erosion potential and allows some suspended sediment to deposit.

Figure D-1. Check dam (US Environmental Protection Agency (USEPA) 1976)

Applicability

2. This practice is limited to use in small open channels which drain 10 acres or less. It should not be used in a perennial stream or in streams which are susceptible to flooding since check dams reduce flow rates and thus increase the chance of flooding. Some specific applications include:

- a. Temporary ditches or swales which, because of their short length of service, cannot receive a nonerodible lining but still need some protection to reduce erosion.
- b. Permanent ditches or swales which for some reason cannot receive a permanent nonerodible lining for an extended period of time.

c. Either temporary or permanent ditches or swales which need protection during the establishment of grass linings.

d. Where excessive grade or overfall conditions occur.

e. Where water is to be lowered from one elevation to another.

3. The minimum capacity of a check dam is that required to confine the peak rate of runoff expected from a 10-year frequency rainfall event, or a higher frequency corresponding to the hazard involved. Peak rates of runoff values used in determining the capacity requirements are outlined in Haan and Barfield (1978).

Planning Considerations

4. Check dams are most commonly constructed of either stone or logs. Log check dams are more economical from the standpoint of material costs since logs can usually be salvaged from clearing operations. However, log check dams require more time and and hand labor to install. Stone for check dams, on the other hand, must generally be purchased. This cost is offset somewhat by the ease of installation.

5. If stone check dams are used in grass-lined channels which will be mowed, care should be taken to remove all the stone from the dam when the dam is removed. This should include any stone which has washed downstream.

6. Since log check dams are embedded in the soil, their removal will result in more disturbance of the soil than will removal of stone check dams. Consequently, extra care should be taken to stabilize the area when log dams are used in permanent ditches or swales.

Sediment removal

7. Some sediment will accumulate behind the check dams. This sediment should be removed when it has accumulated to one-half of the original height of the dam.

Removal

8. Check dams must be removed when their useful life has been completed. In temporary ditches and swales, check dams should be removed and the ditch filled in when it is no longer needed. In permanent structures, check dams should be removed when a permanent lining can be installed. For grass-lined ditches, check dams should be removed when the grass has matured sufficiently to protect the ditch or swale. The area beneath the check dams should be seeded and mulched immediately after the dams are removed.

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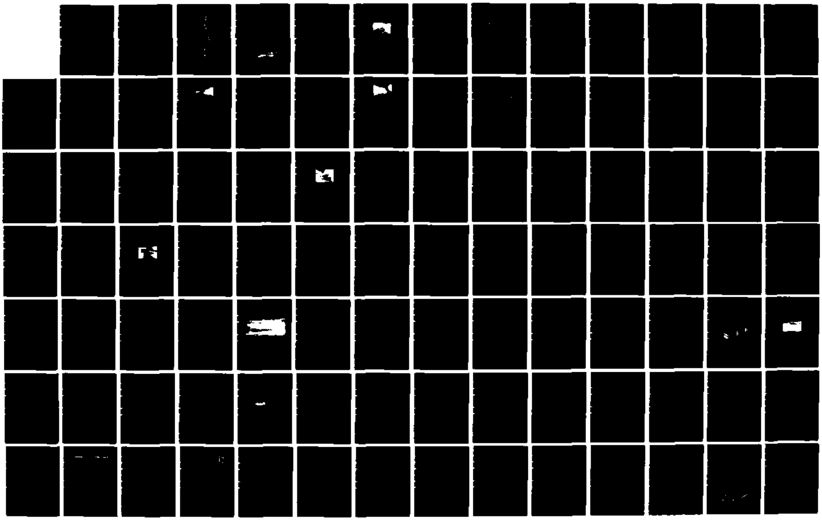

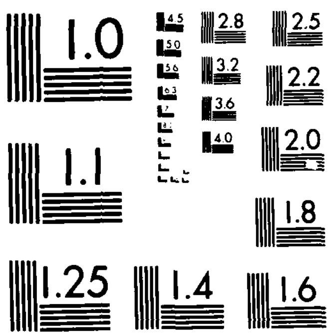

MICROCOPY RESOLUTION TEST CHART

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Design Criteria

9. Formal design is generally required.

   a. Concrete, metal, rock, gabions, wood, Fabriform , etc., may be used in the construction of check dams.

   b. The drainage area of the channel being protected should not exceed 10 acres. The maximum height of the check dam should be 2 ft. The maximum spacing between the dams should be such that the toe of the upstream dam is at the same elevation as the top of the downstream dam (Figure D-2).

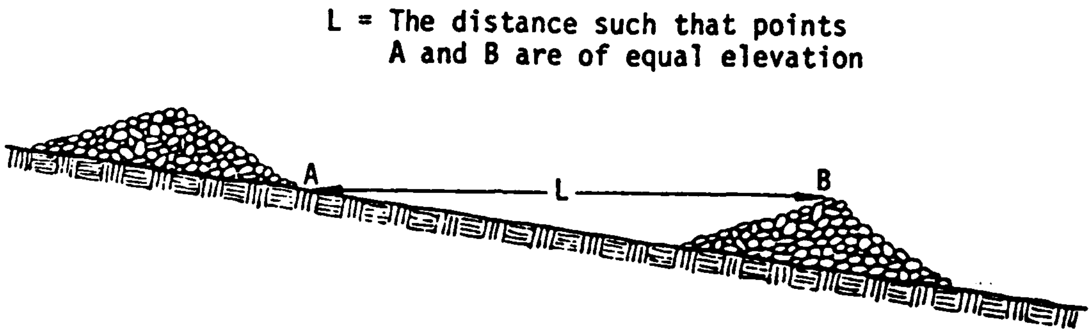


Figure D-2. Spacing between check dams (Virginia Soil and Water Conservation Commission (VSWCC) 1980)

   c. Log check dams should be constructed of 4- to 6-in.-diam logs salvaged from the clearing operations onsite, if possible. The logs should be driven into the streambed a minimum of 18 in. on a line perpendicular to the stream flow (greater depths are required in noncohesive soils). It may be desirable for a group of logs in the middle of the check dam to be driven 6 in. to 1 ft lower to form a weir. This is required in certain areas of the country. This type of check dam is shown in Figures D-3 and D-4.

   d. Intermingled brush and logs (Figures D-3 and D-4) or filter cloth may be attached to the upstream side of the dam to retard the flow and trap additional sediment. If a filter cloth is used, it should be securely stapled to the top of the dam and adequately anchored in the streambed.

   e. Stone check dams should be constructed of 2- to 3-in. stone. The stone should be placed according to the configuration in Figure D-5. Hand or mechanical placement will be necessary to achieve complete coverage of the ditch or swale and to ensure that the center of the dam is lower than the edges, if necessary.

   f. Riprap may be necessary on the downstream side of the dam to protect the streambed from scour.

   g. Riprap, stone, logs, or concrete should be placed in the high energy area at the downstream toe of the check dam in order to prevent undercutting of the structure.

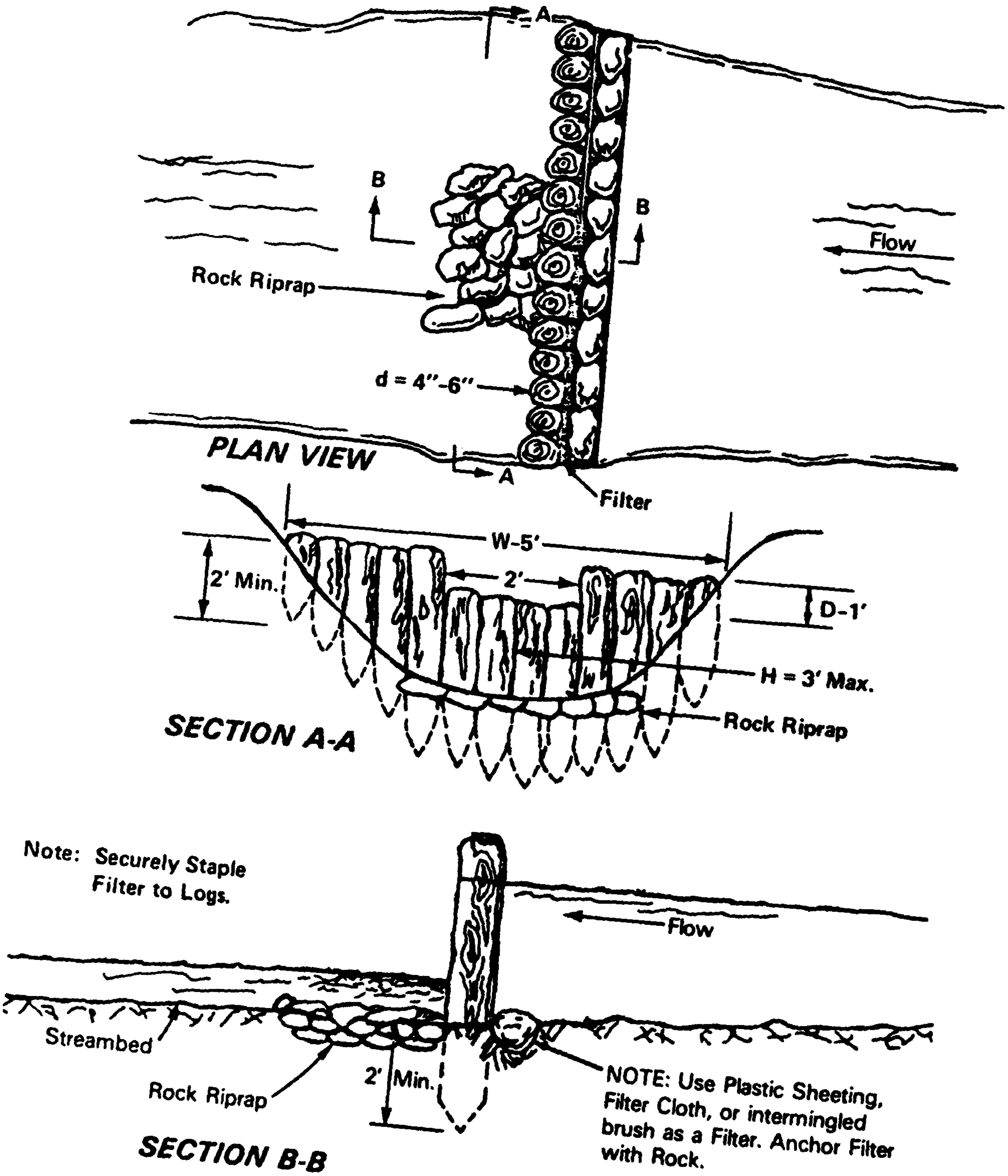


Figure D-3. Log check dam - Type 1 (Richards and Middleton 1978)

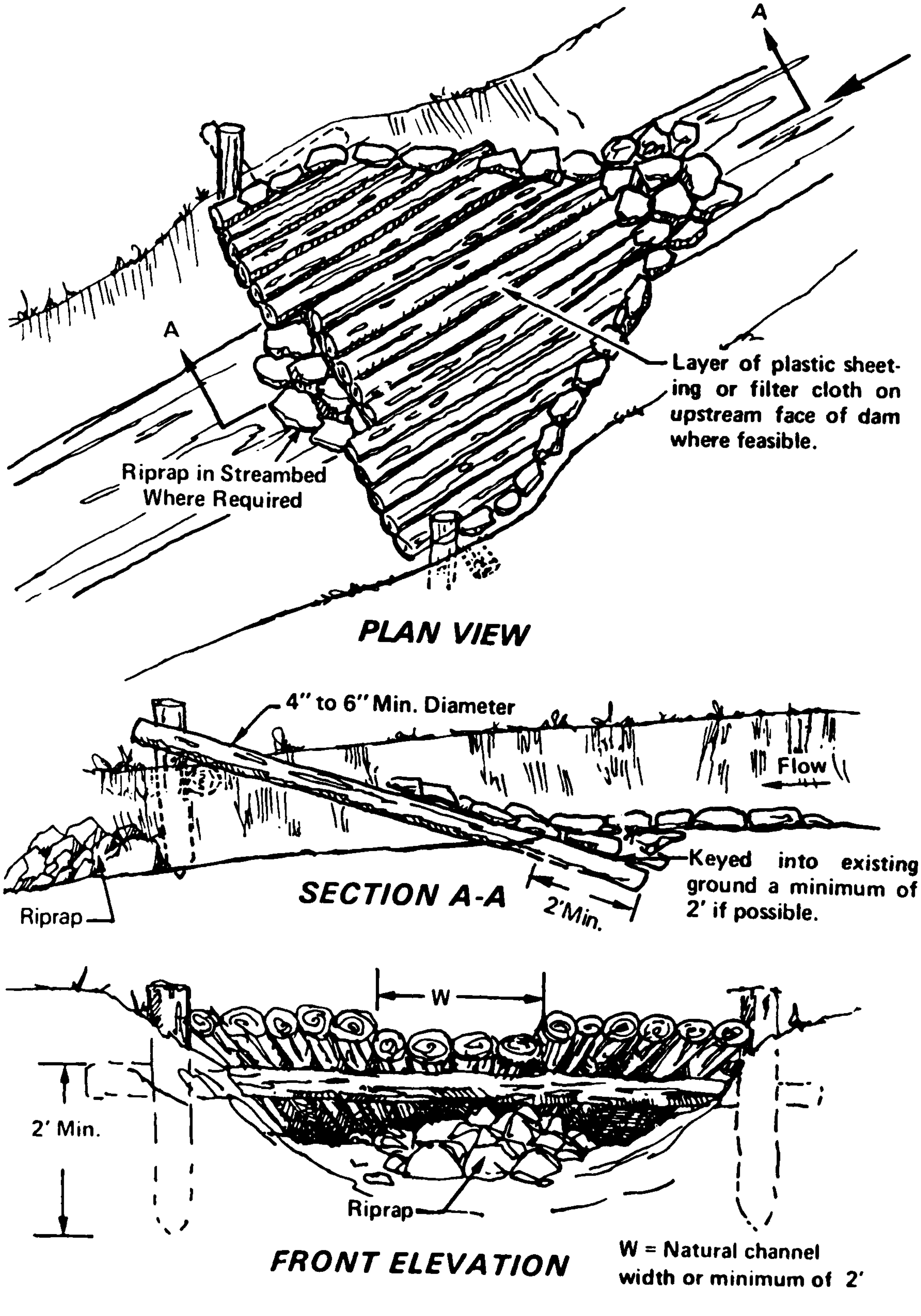


Figure D-4. Log check dam - Type 3 (Richards and Middleton 1978)

h. The check dam should be located in a reasonably straight channel section and particular attention must be given to the effect that new water levels will have on existing natural and man-made features.

i. Site and foundation conditions and aesthetic considerations must be taken into account when selecting materials.

j. Design channel grade above and below the structure should be analyzed to determine if erosion or sediment deposition will be a problem.

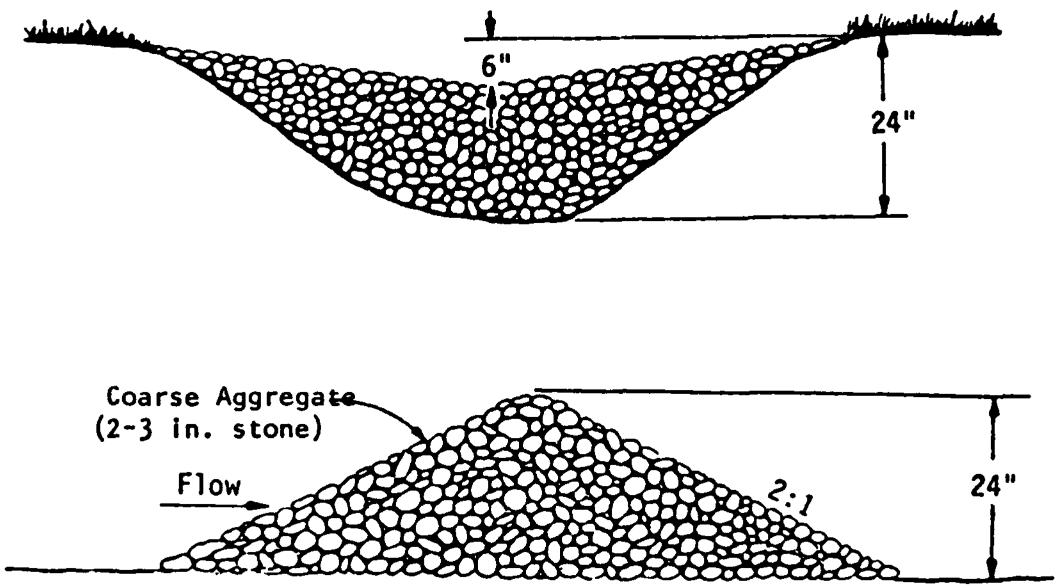


Figure D-5. Rock check dam (VSWCC 1980)

Maintenance

10. Check dams should be inspected periodically to ensure that they are working properly. Inspections, particularly after a significant rainfall, are especially important since these usually cause heavy sediment accumulation, wash-outs, or damage to the filter material. These inspections should ensure that the dam center is lower than the edges. Any erosion around the edges covered by high flows should be corrected immediately.

DIVERSIONS

11. Diversion structures are small, temporary or permanent structures which are used to intercept and convey sheet flow from and to critically disturbed areas to stable outlet points. The types of structures used for this purpose include berms or dikes, ditches or swales, and a combination of these two (Figure D-6).

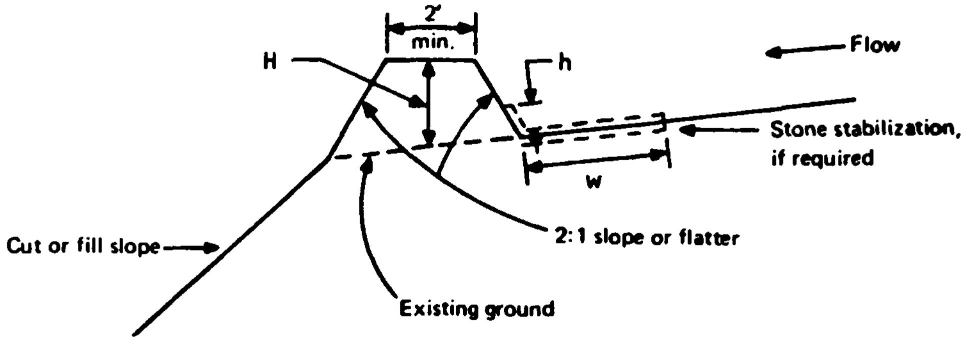
Figure D-6. Photo of combination diversion

12. A dike or berm diversion (Figure D-7) is a temporary ridge of compacted soil placed on the contour above, below, or around a disturbed area. A ditch or swale diversion (Figure D-8) is an excavated, temporary drainageway which is used in the same fashion as the dike. A combination diversion (Figure D-9) is a permanent or temporary drainageway constructed by excavating a shallow ditch along the contour of a hillside and building a soil dike along the downhill side of the ditch with the excavated soil.

Applicability

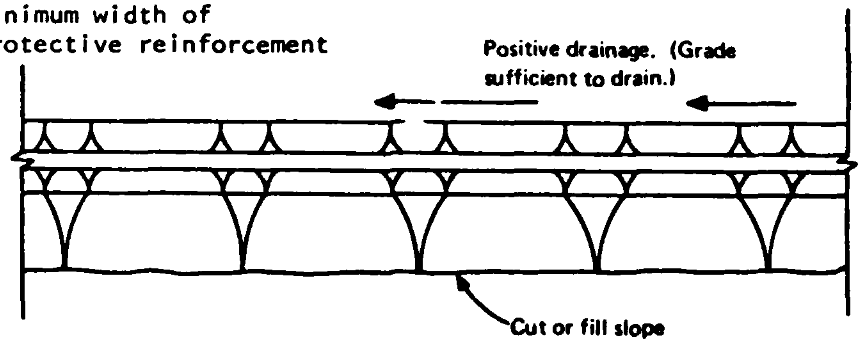
13. Diversion structures are among the most commonly used, effective, and versatile measures of erosion control. These structures can be used to provide perimeter control, slope control, and control of concentrated flow.

14. The function of a diversion structure is to intercept surface runoff before it can cause damage, and to divert the water to a safe disposal area. At Corps construction sites, diversion structures have three primary applications:



H = height of dike
h = minimum height of protective reinforcement
w = minimum width of protective reinforcement

Cross section



Construction Specifications

1. Whenever feasible, the dike should be built before any disturbance begins.

2. All dikes should be machine compacted to prevent failure and should be 85 percent standard density. In wooded areas where top of slope access is limited, diversion dikes can be constructed as a dozer finishes the slope by carrying soil upslope and dumping it at the crest. Compaction is sacrificed in this instance.

3. All diversion dikes should have positive drainage to an outlet.

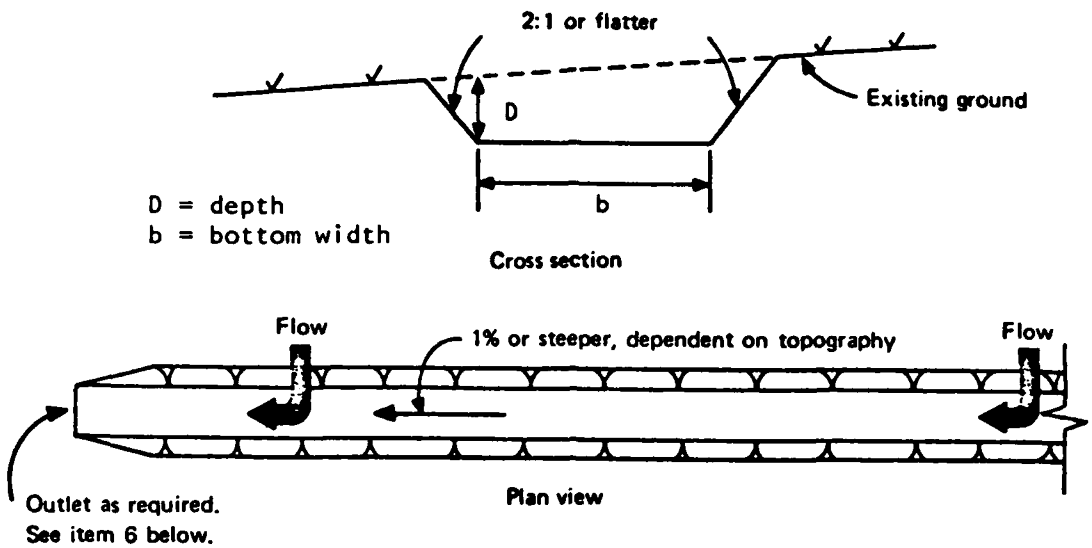
4. A. Diverted runoff from a protected or stabilized area shall outlet directly to an undisturbed stabilized area or into a level spreader or grade stabilization structure.

   B. Diverted runoff from a disturbed or exposed upland area shall be conveyed to a sediment trapping device such as a sediment trap or a sediment basin or to an area protected by any of these practices.

5. Stabilization shall be as specified for Waterways. Stabilization should be applied to the dike within 15 days of construction.

6. Periodic inspection and required maintenance should be provided.

Figure D-7. Diversion dike (USEPA 1976)



Construction Specifications

1. All trees, brush, stumps, obstructions, and other objectionable material should be removed and disposed of so as not to interfere with proper functioning of the swale.

2. The swale should be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein and be free of bank projections or other irregularities which will impede normal flow.

3. Fills should be compacted as needed to prevent unequal settlement that would cause damage in the completed swale.

4. All earth removed and not needed in construction should be spread or disposed of so that it will not interfere with the functioning of the swale.

5. Perimeter swales should have a minimum grade of one percent and the bottom should be level.

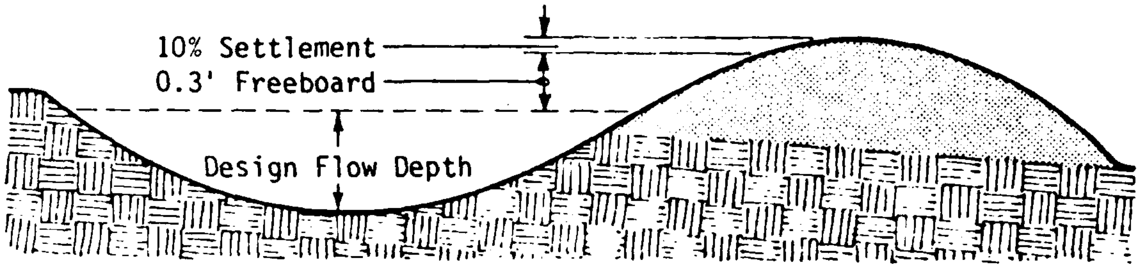
6. A. Diverted runoff from a protected or stabilized upland area should outlet directly onto an undisturbed stabilized area, level spreader, or into a grade stabilization structure.

   B. Diverted runoff from a disturbed or exposed upland area should be conveyed to a sediment trapping device such as a sediment trap or sediment basin or within an area protected by any of these practices.

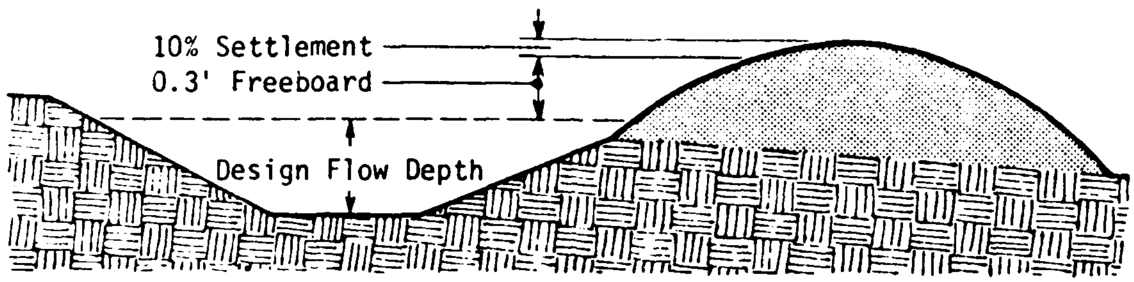
7. Stabilization should be as specified for Waterways.

8. Periodic inspection and required maintenance should be provided.

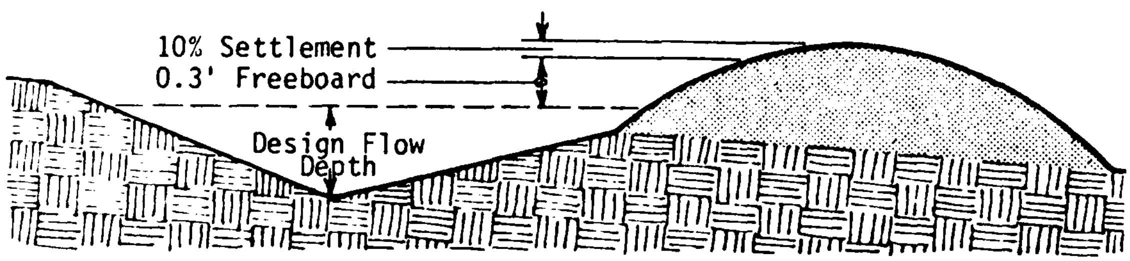
Figure D-8. Diversion (perimeter) swale (USEPA 1976)



Typical Parabolic Diversion



Typical Trapezoidal Diversion



Typical Vee-Shaped Diversion

Figure D-9. Combination diversion (VSWCC 1980)

a. Prevent surface runoff from higher elevated undisturbed or stabilized areas from coming in contact with exposed soil surfaces (graded spoils, cleared areas, roadways, etc.) and causing erosion.

b. Shortening the length of graded slopes (spoil slopes and roadway grades), thereby protecting lower portions of a hillside or roadway from highly erosive surface flow.

c. Prevent sediment-laden runoff from an exposed slope from exiting the construction site without first passing through a sediment detention structure.

15. The dike is the least durable diversion structure, and should only be used to provide temporary protection when relatively small amounts of runoff are anticipated. It can be used above newly constructed fill and cut slopes to prevent excessive erosion of the slope until more permanent drainage features are installed, or vegetation is established. It can also be used on relatively flat slopes before grading to divert sediment-laden runoff into sediment traps or basins. Once the slope is stabilized, the dike is removed. Diversion dikes generally have a life expectancy of 18 months or less.

16. A diversion swale can be constructed at the perimeter of a disturbed area to transport sediment-laden water to a sediment trapping device, such as a sediment trap or sediment basin. The swale is left in place until the disturbed area is permanently stabilized. A diversion swale is also used to prevent storm runoff from entering the disturbed area.

17. While combination diversions can be used as temporary structures, they are primarily used to provide more permanent runoff control by reducing the slope length on long slopes subject to heavy flow concentrations. In addition to intercepting and diverting runoff on, or above, long graded soil slopes, special diversions known as water bars can be used on abandoned access roads to intercept runoff flowing along the roadway and divert it across the roadway to a safe outslope disposal point.

Planning Considerations

18. In selecting the type of structure to be used for a particular application, the following factors must be considered:

a. Ease of installation and, if required, removal.

b. The amount of water to be handled.

c. Ground slope.

d. Required service life.

19. The primary purpose of a diversion dike is to divert overland sheet flow to a stablized outlet or a sediment trapping facility while permanent stabilization of disturbed sloping areas is being established. When used at the top of a slope, the structure protects exposed slopes by keeping upland runoff away. When used at the base of a slope, the structure protects adjacent and downstream areas by diverting sediment-laden runoff to a sediment trapping facility.

20. If the dike is going to remain in place for longer than 30 days, it is very important that it be stabilized with temporary or permanent vegetation. The dike should have a positive grade to ensure drainage, with precautions to prevent erosion due to high velocity flow behind the dike.

21. Construction of diversion dikes is considered to be an economical practice since they use materials available on the site and can usually be constructed with equipment needed for site grading. Although diversion dikes are primarily temporary structures, they can be made permanent with more stringent design criteria.

22. Diversions can be useful tools for managing surface water flows and preventing soil erosion. On moderately sloping areas, they may be placed at intervals to trap and divert flow before it has a chance to become so concentrated that excessive rill erosion occurs. They may be placed at the top of cut or fill slopes to keep runoff from upland drainage areas off the slope. They can also be used to protect structures, parking lots, adjacent properties, and other special areas from flooding, and to divert nondisturbed area drainage from a sediment pond. When properly coordinated into the landscape design of a site, diversions can be visually pleasing as well as functional.

23. As with any earthen structure, it is very important to establish adequate vegetation as soon as possible after installation. It is equally important to stabilize the drainage area above the diversion so that sediment will not enter and accumulate in the diversion channel. If this stabilization is not possible, then channel maintenance is necessary.

Design Criteria

24. A general design is necessary whether the structure is designed for temporary or permanent use. The elements of design to be considered include (a) location, (b) capacity, (c) velocity and grade, (d) channel cross section, (e) ridge cross section, (f) outlets, and (g) stabilization.

Location

25. Diversion location should be determined by considering outlet conditions, topography, land use, soil type, length of slope, seep planes (when seepage is a problem), and the site layout. In general, a diversion should be placed in the following locations:

a. Upgradient of any disturbed area to reduce the volume of surface runoff which will attack the disturbed area.

b. Along steep or long slopes to control sheet flow and reduce the slope length and steepness factor.

c. Along the base or toe of denuded and/or disturbed slopes to collect sediment-laden runoff and convey it to a settling basin.

d. Around soil stockpiles.

e. Along the sides of access roads.

Capacity

26. The diversion should be designed and constructed so that it will have the capacity to carry, as a minimum, the peak discharge from the design storm with freeboard of not less than 0.3 ft (Figure D-9). The design storm for a temporary diversion is a 2-year, 24-hr duration storm, whereas the design storm for a permanent diversion is a 10-year, 24-hr duration storm.

Velocity and grade

27. The channel velocity is a function of the channel slope and type of channel lining among other factors. The minimum channel gradient is generally determined by the site topography. Consequently, the design process generally consists of selecting a channel lining suited for the calculated velocities. Maximum permissible flow velocities for various types of lining material and grades are provided in Table D-1. In all cases, however, diversions should have a minimum grade of one percent to ensure drainage to an adequate outlet.

Channel cross section

28. This design criterion applies only for swales and combination diversions. The shape of the channel may be parabolic, trapezoidal, or vee-shaped as shown in Figure D-9. Additional design information is provided under Waterways. A minimum channel depth of one foot and a minimum bottom width of 7 ft should be provided.

Ridge cross section

29. This design criterion applies only for dikes and combination diversions. The ridge must be designed with stable side slopes which should not in any case be steeper than 2:1. Typical ridge cross sections are illustrated in Figures D-7 and D-9.

30. The minimum height of the ridge should be based on the height required to convey the design storm. A minimum freeboard of 0.3 ft should be provided. The final design height should not be less than 18 in., measured

Table D-1

Maximum Permissible Design Velocities for

Stable Diversion*

Cover	Range of Channel Gradient, percent	Permissible Velocity fps
Vegetative**		
(1) Tufcote	0 to 5.0	6
Midland	5.1 to 10.0	5
Coastal bermudagrass	Over 10.0	4
(2) Reed canarygrass	0 to 5.0	5
Kentucky 31 tall fescue	5.1 to 10.0	4
Kentucky bluegrass	Over 10.0	3
(3) Red fescue Redtop	0 to 5.0	2.5
(4) Annuals† Small grain (rye, oats, barley, millet) Ryegrass	0 to 5.0	2.5
Riprap lining		-See Riprap-
Natural soil		-See Waterways-

* US Department of Agriculture, Soil Conservation Service (USDA, SCS) 1975; Fortier and Scobey (1926).
** To be used only below stabilized protected areas.
† Used only as temporary protection until permanent vegetation is established.

from the existing ground at the upslope toe to the top of the ridge. However, a minimum height of 12 in. may be allowed for active grading sites at the end of each day's operations.

31. The top width of the ridge should not be less than two ft.

Outlets

32. Each diversion must have a stable outlet constructed and stabilized prior to the operation of the diversion. The outlet may be a natural or constructed waterway, a stabilized open channel, a grade stabilization structure, a sediment trap or basin, a level spreader, or any of a variety of downdrain structures. In all cases, the diversion must discharge into the outlet in such a manner as not to cause erosion.

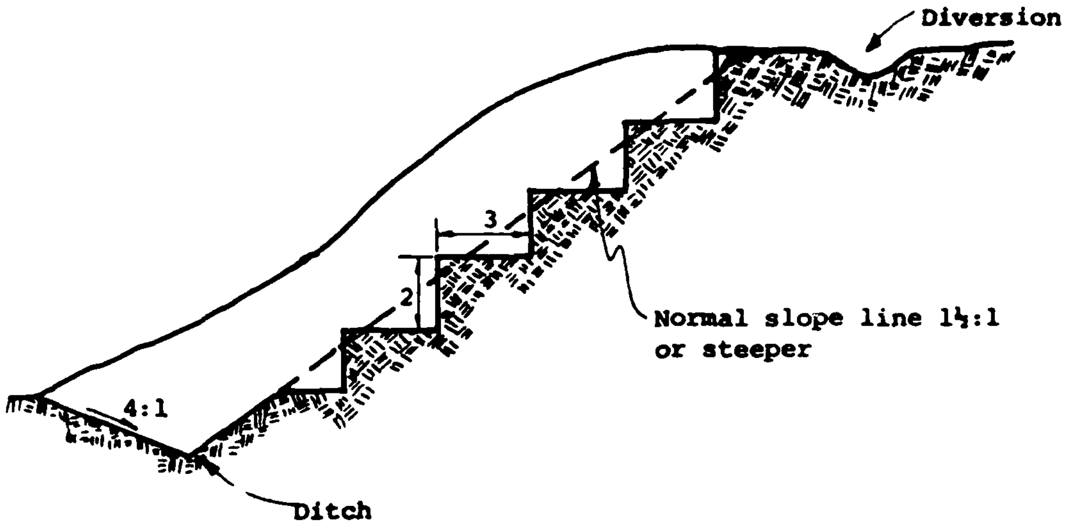
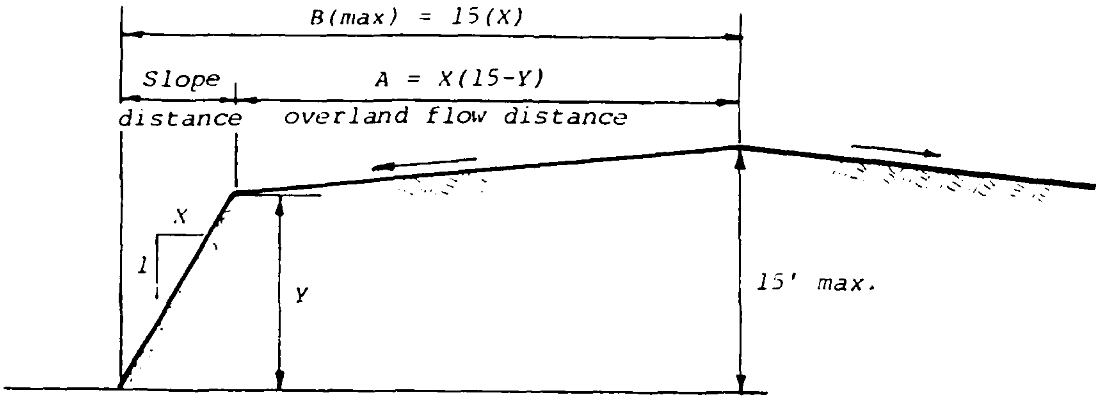


Figure D-16. Typical section of serrated cut slope (USDA, SCS 1975)



The maximum total horizontal overland-flow-plus-slope distance (B) should not exceed 15 times the side slope (X) of the cut or fill slope. Maximum allowable overland flow* distance (in feet) to the top of the slope with no diversion of surface water is determined by use of the formula A = X(15-Y),

where:

A = Maximum overland flow distance in feet to slope crest
X = Side slope; horizontal distance in feet to 1 ft vertical
Y = Vertical interval; height of cut/fill slope in feet measured vertically from bottom elevation of slope to slope crest

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* If maximum allowable overland flow is exceeded, surface water should be diverted from the slope face and carried to a stable outlet, or conveyed downslope with a designed structure.

Figure D-15. Typical section of a slope (USDA, SCS 1975)

debris, and other objectional material that would interfere with or prevent construction of satisfactory fills. It should be free of stones over 2 in. in diameter where compacted by hand or mechanical tampers or over 6 in. in diameter where compacted by rollers or other equipment. Frozen material should not be placed in the fill nor should the fill material be placed on a frozen foundation.

i. Stockpiles, borrow areas, and spoil areas should be shown on the plans.

j. All disturbed areas should be stabilized structurally or vegetatively (Figure D-17).

(3) The flow length within a bench should not exceed 800 ft unless accompanied by appropriate design and computations (see Diversions).

d. Surface water should be diverted from the face of all cut and/or fill slopes by the use of diversions, ditches, and swales or conveyed downslope by the use of a designed structure, except where:

(1) The length of overland flow (in feet) to the crest of the slope does not exceed the distance "A" given in Figure D-15 and the following example for any combination of side slopes and vertical intervals.

Example: Determine the maximum allowable overland flow distance, A , for a 3:1 side slope with a vertical interval of 7 ft.

$(X = 3)\ (Y = 7)$
$A = X(15-Y)$
$A = 3(15-7)$
$A = 24$ ft

(2) The face of the slope is stabilized and the face of all graded slopes is protected from surface runoff until they are stabilized.

(3) The face of the slope is not subjected to any concentrated flows of surface water from natural drainageways, graded swales, downspouts, etc.

e. Serrated cut slopes should be constructed so as to facilitate long-lasting vegetative stabilization. These serrations should be made in rippable rock with conventional equipment as the excavation is made. Each step or serrate should be constructed on the contour and have steps cut at nominal 2-ft intervals with nominal 3-ft horizontal shelves. These steps will vary depending on the slope ratio of the cut slope. The normal slope line is 1-1/2:1. These steps will weather and act to hold moisture, lime and fertilizer, and seed, and to produce a much quicker and longer lived vegetative cover and slope stabilization. Overland flow is diverted from the top of all serrated cut slopes and is carried to a suitable outlet (Figure D-16).

f. Subsurface drainage should be provided where necessary to intercept seepage that would otherwise affect slope stability or create excessively wet site conditions that would hinder or prohibit vegetative establishment (see Subsurface Drains).

g. Slopes should not be created so close to property lines as to endanger adjoining properties without adequately protecting such properties against erosion, slippage, settlement, subsidence, or other related damages.

h. Materials for earth fills should be obtained from designated areas. Except for approved landfills, the fill material should be free of brush, rubbish, rocks, logs, stumps, building

49. Land grading is the reshaping of the existing topography in accordance with a plan determined by engineering survey and layout.

50. The purpose of land grading is to provide for erosion control and vegetative establishment on those areas where the existing topography is to be reshaped by grading according to plan.

51. The grading plan should use existing topography and desirable natural surroundings to avoid extreme grade modifications whenever possible. Information submitted will provide sufficient topographic surveys and soil investigations to determine limitations that must be imposed on the grading operations related to slope stability, effect on adjacent properties and drainage patterns, measures for drainage and water removal, vegetative treatment, etc.

52. The plan must show existing and proposed contours of the area to be graded. The plan should also include practices for erosion control; slope stabilization; and safe disposal of runoff water and drainage, such as waterways, lined ditches, reverse slope benches (including grade and cross section), grade stabilization structures, and surface and subsurface drains. The plan should also include scheduling and phasing of these practices. The following should be incorporated into the plan:

a. Provisions should be made to safely conduct surface runoff to storm drains, protected outlets, or to stable water courses to ensure that surface runoff will not damage slopes or other graded areas (see Waterways, Diversions, and Downdrain Structures).

b. Cut and fill slopes should not be steeper than 2:1. Where the slope is to be mowed, the slope should be no steeper than 3:1 (4:1 is preferred because of safety factors related to mowing steep slopes).

c. Reverse slope benches or diversions should be provided whenever the vertical interval (height) of any 2:1 through 5:1 slope exceeds 15 ft. Benches should be located so as to divide the slope face as equally as possible and should convey the water to a stable outlet. Soils, seeps, rock outcrops, etc., should also be taken into consideration when designing benches.

(1) Benches should be wide enough to accommodate the construction equipment in use and provide for ease of maintenance.

(2) Benches should be designed with a reverse slope of 5:1 or flatter to the toe of the upper slope and with a minimum of 1 ft in depth. Bench gradient to the outlet should be between 1 and 2 percent.

Table D-3

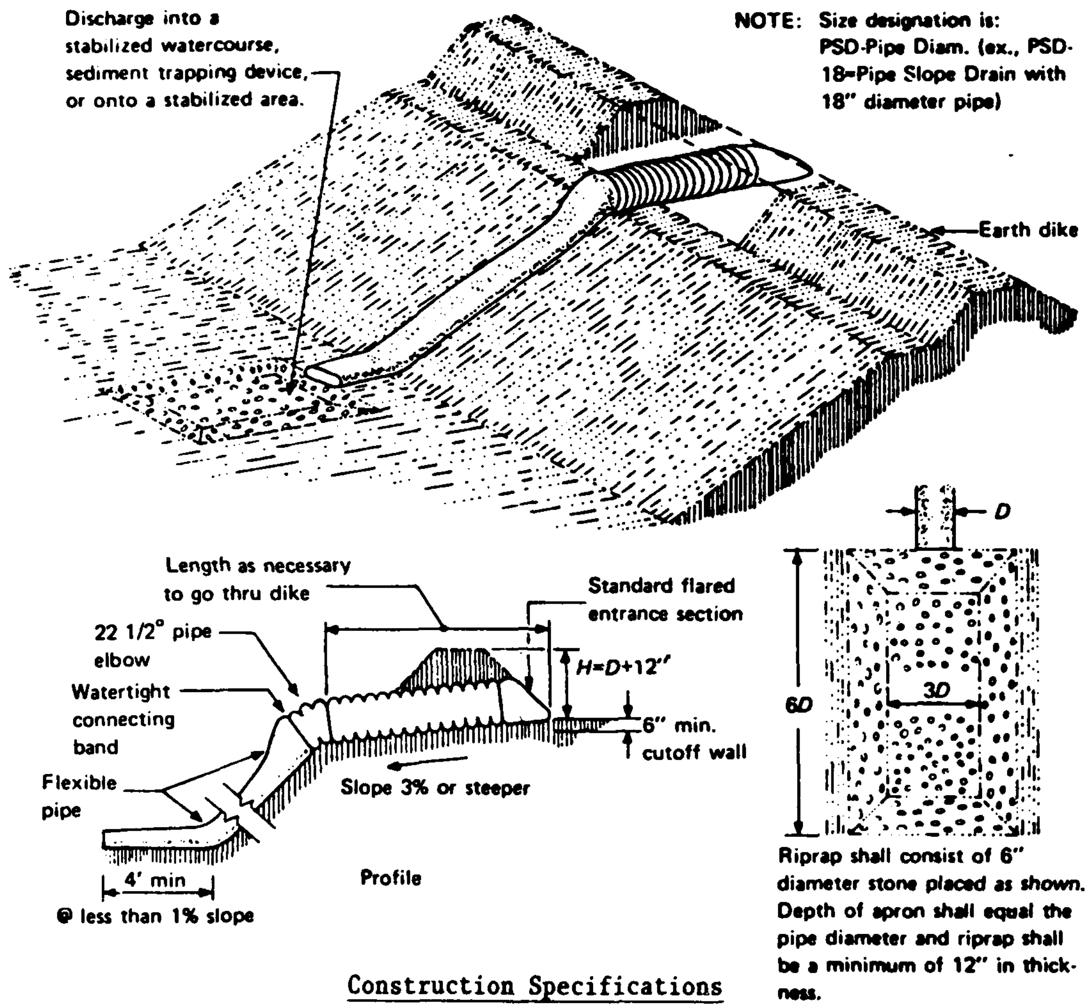
Size of Pipe/Tubing*

Maximum Drainage Area, acres	Pipe/Tubing Diameter, D , in.	Size, Pipe Slope Drain
0.5	12	PSD-12
1.5	18	PDS-18
2.5	21	PDS-21
3.5	24	PDS-24
5.0	30	PDS-30

* USEPA (1976).

Maintenance

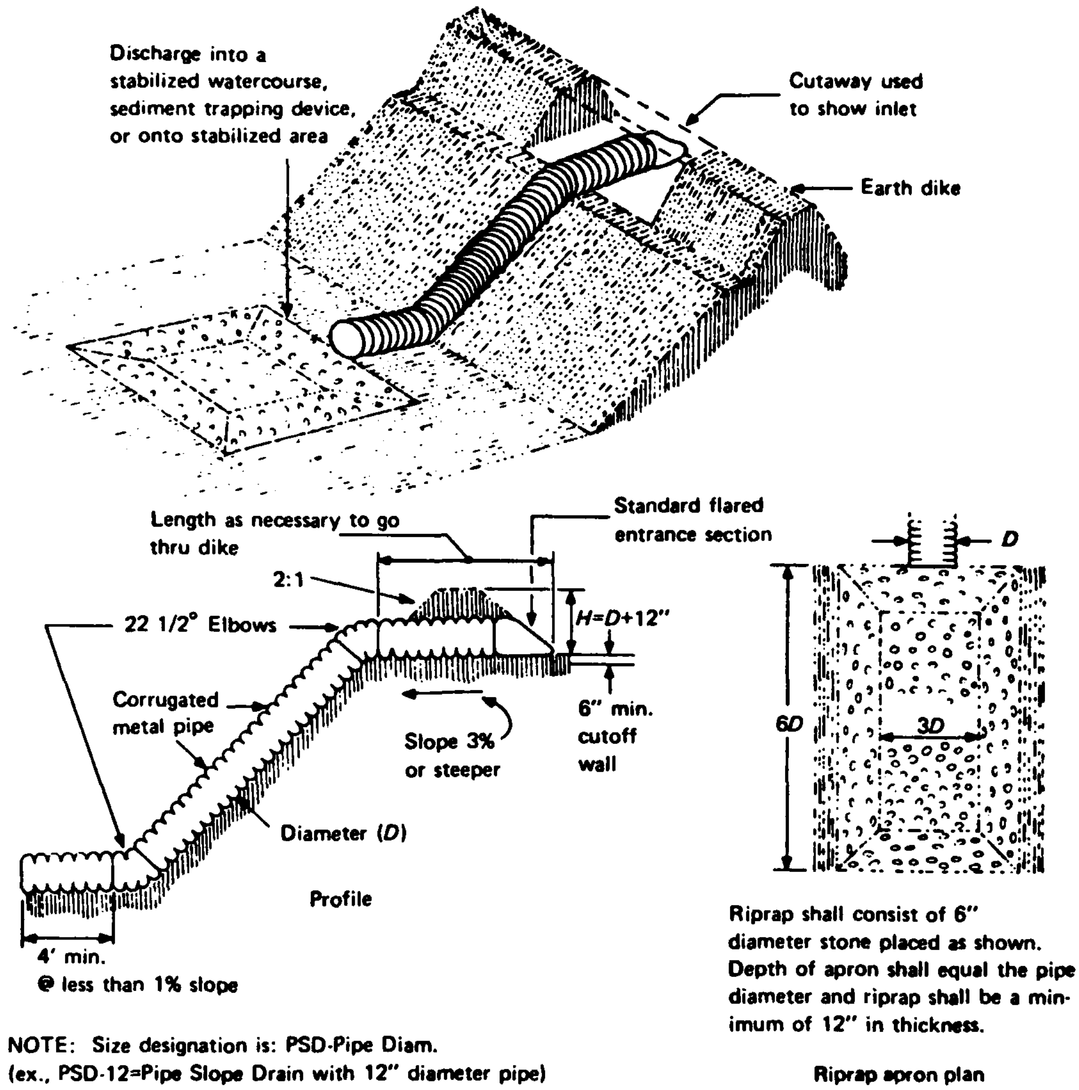
48. The slope drain structure should be inspected weekly and after every storm for clogging or damage and repairs made, if necessary. In below-freezing weather, check to ensure that sides of collapsed downdrain are not frozen together. Inlet sections should be checked for indications of piping along metal sections. Anchors should be resecured as necessary. The operator should avoid placing any material on and prevent traffic across the slope drain.



Construction Specifications

1. The inlet pipe should have a slope of 3 percent or steeper.
2. The top of the earth dike over the inlet pipe and those dikes carrying water to the pipe should be at least 1 foot higher at all points than the top of the inlet pipe.
3. The inlet pipe should be corrugated metal pipe with watertight connecting bands.
4. The flexible tubing should be the same diameter as the inlet pipe and should be constructed of a durable material with hold-down grommets spaced 10 feet on centers.
5. The flexible tubing should be securely fastened to the corrugated metal pipe with metal strapping or watertight connecting collars.
6. The flexible tubing should be securely anchored to the slope by staking at the grommets provided.
7. A riprap apron should be provided at the outlet. This should consist of 6-in. diameter stone placed as shown above.
8. The soil around and under the inlet pipe and entrance section should be hand tamped in 4-in. lifts to the top of the earth dike.
9. Follow-up inspection and any needed maintenance should be performed after each storm.

Figure D-14. Pipe slope drain (flexible) (USEPA 1976)



1. The inlet pipe should have a slope of 3 percent or steeper.

2. The top of the earth dike over the inlet pipe and those dikes carrying water to the pipe should be at least 1 foot higher at all points than the top of the inlet pipe.

3. The pipe should be corrugated metal pipe with watertight connecting bands.

4. A riprap apron should be provided at the outlet. This should consist of 6-in. diameter stone placed as shown above.

5. The soil around and under the inlet pipe and entrance sections should be hand tamped in 4-in. lifts to the top of the earth dike.

6. Follow-up inspection and any needed maintenance should be performed after each storm.

Figure D-13. Pipe slope drain (rigid) (USEPA 1976)

Figure D-12. Rigid pipe

Planning Considerations

45. Temporary slope drains provide valuable protection for exposed slopes which are not stabilized and therefore particularly susceptible to erosion. These slopes are usually most vulnerable before final grading or before installation of any permanent drainage systems. When used in conjunction with diversion dikes, temporary slope drains can be used to convey stormwater from the entire drainage area above a slope to the base of the slope without erosion. It is very important that these temporary structures be installed properly since their failure will often result in severe gully erosion. The entrance section must be securely entrenched, all connections must be watertight, and the conduit must be staked securely.

Design Criteria

46. Pipe slope drains are to be sized as shown in Table D-3. The earth dike height at the entrance to the pipe slope drain should be equal to, or greater than, the diameter of the pipe, D , plus 12 in.

47. The pipe slope drain should outlet onto a riprap apron and then into a stabilized area or stable watercourse. Use a sediment-trapping device to trap sediment from any sediment-laden water conveyed by the pipe slope drain.

Table D-2

Bottom Widths and Maximum Drainage Areas (USEPA 1980)

Size*	Bottom Width, b ft	Maximum Drainage Area, acres
A-2	2	5
A-4	4	8
A-6	6	11
A-8	8	14
A-10	10	18
B-4	4	14
B-6	6	20
B-8	8	25
B-10	10	31
B-12	12	36

* The size is designated with a letter and a number, such as A-6 which means a chute or flume in Size Group A with a 6-ft width. The selected size should appear on the plans.

Downdrain Structures - Pipe Slope Drains

43. A pipe slope drain consists of either a rigid pipe (Figures D-12 and D-13) or flexible tubing (Figure D-14), together with a prefabricated entrance section. The pipe is temporarily placed to extend from the top to the bottom of a slope.

Applicability

44. Pipe slope drains are used where a concentrated flow of surface runoff must be conveyed down a slope without causing erosion. They are also used on slopes before permanent drainage structures are installed. The maximum drainage areas for the eastern humid regions should be roughly 5 acres while a larger drainage area can be used for the western, more arid regions.

Design Criteria

39. The following general design criteria are used for temporary structures. Permanent structures will require a formal design.

a. Size Group A

(1) The height (H) of the dike at the entrance must be at least 1.5 ft.

(2) The depth (d) of the chute down the slope must be at least 8 in

(3) The length (L) of the inlet and outlet sections must be at least 5 ft.

b. Size Group B

(1) The height (H) of the dike at the entrance must be at least 2 ft.

(2) The depth (d) of the chute down the slope must be at least 10 in.

(3) The length (L) of the inlet and outlet sections must be at least 6 ft.

40. Each size group has various bottom widths and allowable drainage areas as shown in Table D-2. The drainage areas listed in Table D-2 may be increased by 50 percent if a minimum of 75 percent of the area will have good grass or woodland cover throughout the life of the structure. The same drainage areas may be increased by 25 percent if a minimum of 75 percent of the area will have a good mulch cover throughout the life of the structure.

41. Outlets of paved flumes must be protected from erosion. In addition, each paved flume may need an energy dissipator. Larger energy dissipators may be similarly designed for larger flume cross sections. When a paved chute or flume of Size Group B is used, the velocity at its outfall should be checked for erosion potential downstream.

Maintenance

42. Before permanent stabilization of the slope, the structure should be inspected after each rainfall and damages to the slope or paved flume repaired immediately. After the slope is stabilized, little maintenance should be required.

Construction Specifications

1. Place the structure on undisturbed soil or on well-compacted fill.

2. The cut or fill slope should not be steeper than 1.5 horizontal to 1 vertical (1.5:1) and not flatter than 20:1.

3. The top of the earth dike at the entrance and the dikes carrying water to the entrance should not be lower at any point than the top of the lining at the entrance of the structure.

4. Extend the lining at the structure entrance the distance, H, above the lining crest as shown in Figure D-10.

5. Place the lining by beginning at the lower end and proceeding up the slope to the upper end. The lining should be well-compacted, free of voids, and reasonably smooth.

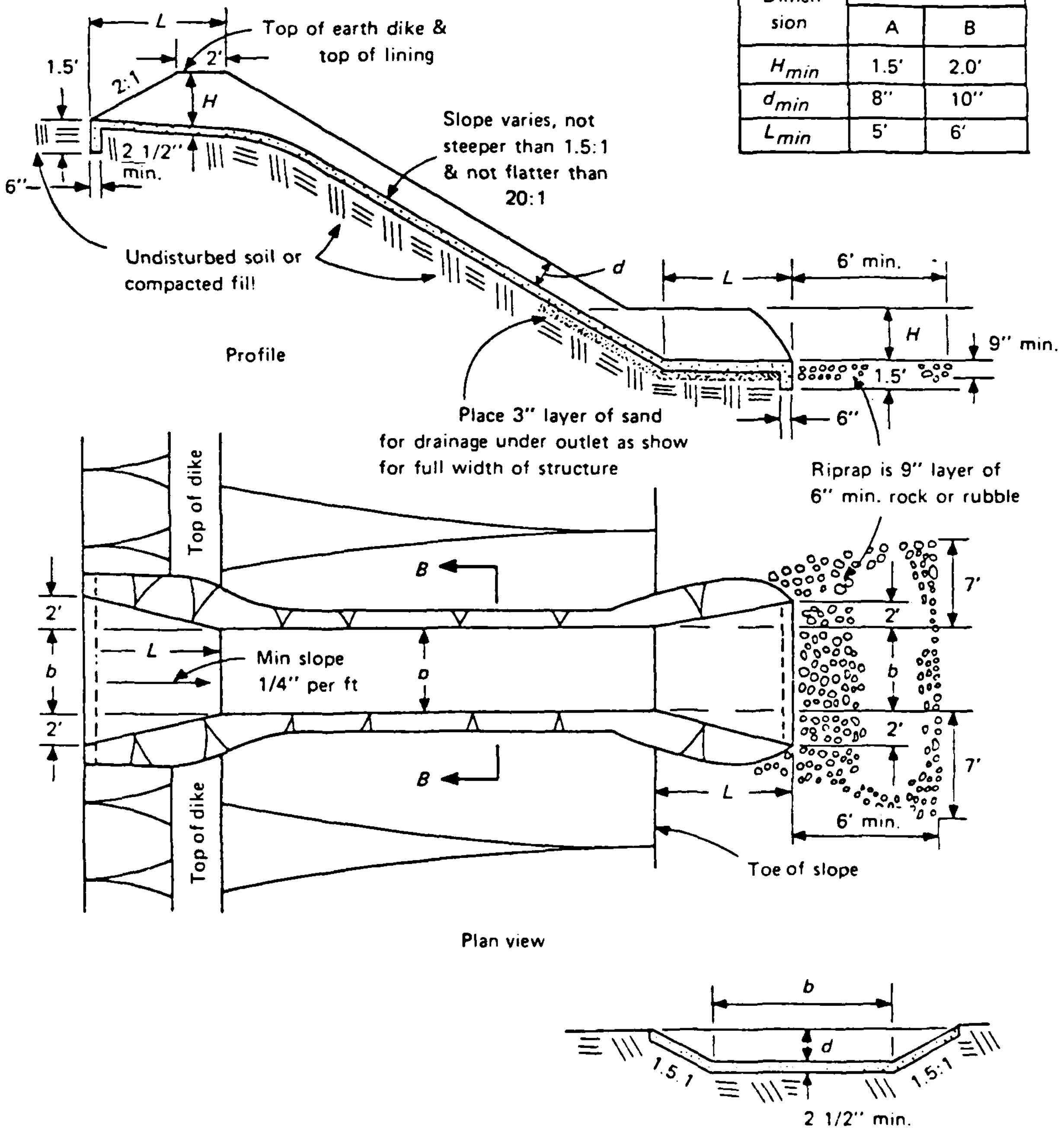
6. The entrance floor at the upper end of the structure should slope toward the outlet between one-quarter and one-half inch per foot.

7. The cut-off walls at the entrance and at the end of the discharge aprons should be continuous with the lining.

8. The lining should consist of portland cement, concrete, bituminous concrete, or comparable nonerodible material, such as riprap.

9. Erosion at the outlet should be prevented by using an adequately designed energy dissipator.

Figure D-11. Grouted rock chute



Dimension	Size Group	
	A	B
H_{min}	1.5'	2.0'
d_{min}	8"	10"
L_{min}	5'	6'

Figure D-10. Paved chute or flume (USEPA 1976)

DOWNDRAIN STRUCTURES

35. Downdrain structures are stabilized channels or pipes used to conduct concentrated runoff safely down a slope. They can be temporary or permanent and are often used to help dispose of water collected by diversion structures. Commonly used downdrain structures include the paved chute or flume and the pipe slope drain (pipe drop structure).

Downdrain Structures - Paved Chute or Flume

36. A paved chute or flume (Figure D-10) is a channel lined with bituminous concrete, portland cement, concrete, or comparable nonerodible material (such as grouted riprap), placed to extend from the top to the bottom of a slope (Figure D-11). Temporary flumes can also be composed of plastic sheets, metal, fiber mats, stone gutter, or half-round pipe.

Applicability

37. A paved chute or flume is used where a concentrated flow of surface runoff must be conveyed down a slope without causing erosion. For temporary structures built according to the following design criteria, the maximum allowable drainage area is 36 acres (USEPA 1976).

Planning Considerations

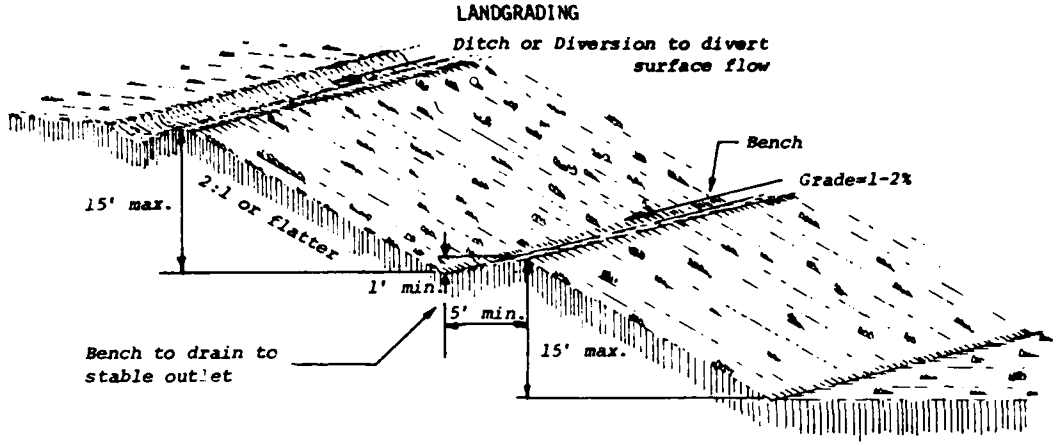
38. Paved flumes are an excellent means of conveying concentrated runoff from the top to the bottom of a slope without causing erosion. When used with diversion structures, paved flumes can be used to convey runoff from the entire drainage area above a slope. Permanent flumes are very useful when needed throughout the lifetime of the project. For nonpermanent slopes, temporary flumes can offer valuable protection of exposed slopes. It is very important that these structures be installed properly since their failure will often result in severe gully erosion. The entrance section should be securely entrenched, all connections should be watertight, and the conduit should be staked securely.

Stabilization

33. Once construction is completed, stabilization of the soil surface must be accomplished as soon as possible. Vegetative covers listed in Table D-1 should be established as soon as possible. If anticipated velocities are greater than 6 fps, then a nonvegetative material such as riprap lining should be considered.

Maintenance

34. Diversion structures should be inspected approximately every 2 weeks and after every substantial storm event. Repairs should be made whenever necessary. Sediment removal from the ditch line should be made when necessary to maintain the discharge capacity of the structure. Vegetative cover which has failed to establish or otherwise failed should be promptly reseeded and mulched.



Construction Specifications

1. All graded or disturbed areas including slopes should be protected during clearing and construction in accordance with the approved sediment control plan until they are permanently stabilized.
2. All sediment control practices and measures should be constructed, applied, and maintained in accordance with the approved sediment control plan.
3. Topsoil required for the establishment of vegetation should be stockpiled in an amount necessary to complete finished grading of all exposed areas.
4. Areas to be filled should be cleared, grubbed, and stripped of topsoil to remove trees, vegetation, roots, or other objectionable material.
5. Areas which are to be topsoiled should be scarified to a minimum depth of 3 in. proper to placement of topsoil.
6. All fills should be compacted as required to reduce erosion, slippage, settlement, subsidence, or other related problems. Fill intended to support buildings, structures, and conduits, etc., should be compacted in accordance with local requirements or codes.
7. All fill to be placed and compacted in layers not to exceed 8 in. in thickness.
8. Except for approved landfills, fill material shall be free of brush, rubbish, rocks, logs, stumps, building debris, and other objectionable material that would interfere with or prevent construction of satisfactory fills.
9. Frozen materials or soft, mucky, or highly compressible materials should not be incorporated into fills.
10. Fill should not be placed on a frozen foundation.
11. All benches should be kept free of sediment during all phases of development.
12. Seeps or springs encountered during construction should be handled in accordance with Construction Specifications for Subsurface Drains or other approved method.
13. All graded areas should be permanently stabilized immediately following finished grading.
14. Stockpiles, borrow areas, and spoil areas should be shown on the plans.

Figure D-17. Slope detail (with bench) (USDA, SCS 1975)

LEVEL SPREADER

53. A level spreader (Figure D-18) is an outlet constructed at zero percent grade across the slope. The purpose of the structure is to convert a concentrated flow of sediment-free runoff (e.g., diversion outlets) into sheet flow and to discharge it at nonerosive velocities onto undisturbed areas stabilized by existing vegetation.

Applicability

54. The level spreader is used only in those situations where the spreader can be constructed on undisturbed soil, where the area directly below the level lip is stabilized by existing vegetation, where the drainage area above the spreader is stabilized by existing vegetation, and where the water will not be reconcentrated immediately below the point of discharge.

Planning Considerations

55. The level spreader can be used as a stable outlet for concentrated flows and for sediment-laden flows. If properly constructed, the level spreader will significantly reduce the velocity of concentrated stormwater and spread it uniformly over a stable undisturbed area.

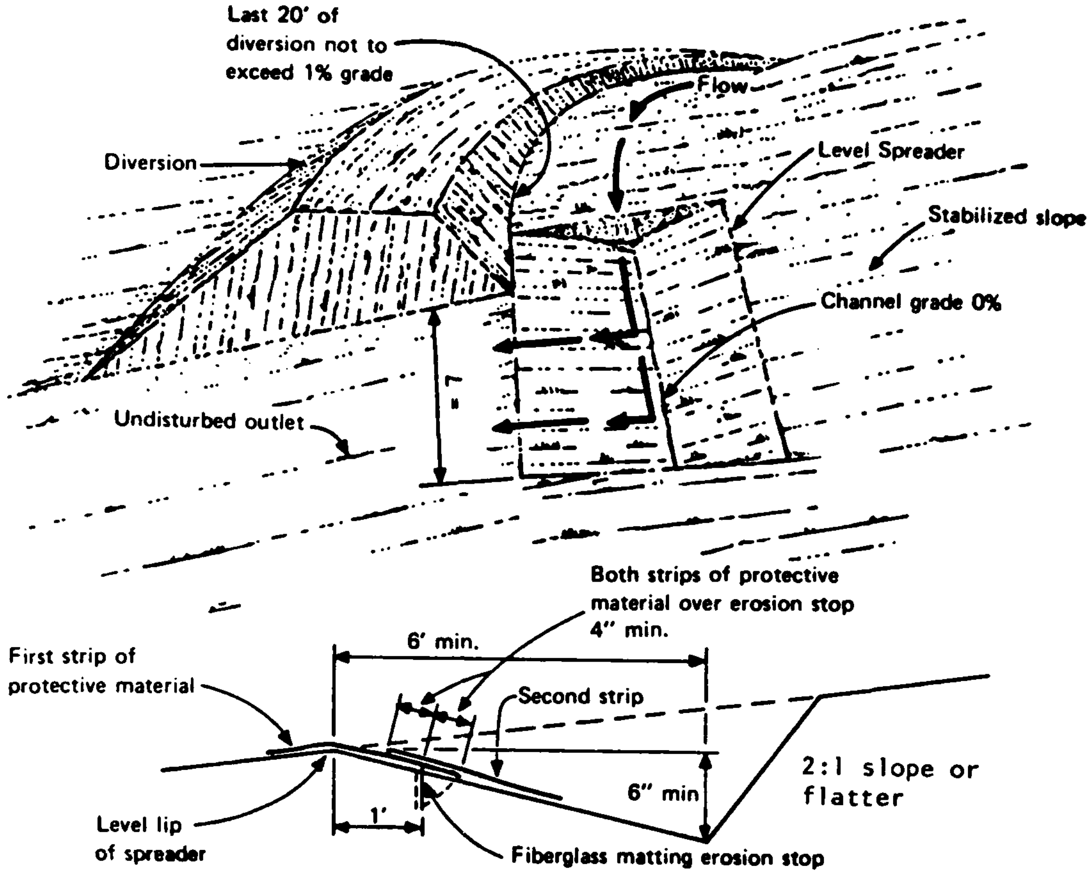
56. The practice is relatively easy and inexpensive to install. However, particular care must be taken during construction to ensure that the lower lip of the structure is level. Depressions in the lip will tend to concentrate flow at these points causing erosion resulting in failure of the outlet. Regular maintenance is essential for this practice.

Design Criteria

57. No formal design is required. The following criteria must be met.

Flow rate

58. The maximum flow rate of a level spreader should be 1 cfs per foot of length, based on the peak rate of flow from the design storm.



Construction Specifications

1. Level spreaders should be installed under the direct supervision of the Project Engineer.
2. The entrance to the spreader must be shaped in such a manner as to ensure that runoff enters directly onto the zero percent channel.
3. Construct level lip on zero percent grade to ensure uniform spreading of sediment-free runoff (converting channel flow to sheet flow).
4. Level spreader should be constructed on undisturbed soil (not on fill).
5. A fiberglass matting erosion stop should be placed vertically and at least six inches deep in a slit trench one foot back of the level lip and parallel with the lip. This erosion stop should extend the entire length of the level lip and should be trimmed after backfilling with tamped soil so that the upper edge is flush with the soil surface.
6. The entire level lip area should be protected by placing two strips of jute or excelsior protective material as shown.
7. The entrance channel should not exceed a one percent grade for at least 20 feet before entering spreader.
8. Storm runoff converted to sheet flow should outlet onto stabilized areas.
9. Periodic inspection and required maintenance should be provided.

Figure D-18. Level spreader (USEPA 1976)

Length

59. Spreader length can be determined by estimating the flow expected from a 10-year storm (Q_{10}), and selecting the appropriate length from the following guidelines:

Design Flow, Q_{10} cfs	Minimum Length ft
0-10	10
10-20	20
20-30	30
30-40	40
40-50	50

60. An acceptable simplified method indicates that the length should be equal to 5 ft per acre of drainage area. For this, the minimum length should be 5 ft. When discharge is to a slope steeper than 4:1 or the soil is highly erodible, the length of the level spreader should be increased.

Width

61. The minimum acceptable width is 6 ft (Figure D-18).

Depth

62. The depth of the level spreader as measured from the lip must be at least 6 in. The depth must be uniform across the entire length of the measure (Figure D-18).

Grade

63. Grade must be as follows:

a. The last 20 ft of a dike or diversion entering a level spreader should be less than or equal to 1 percent grade (Figure D-18).

b. The grade of the level spreader should be zero percent.

Back slope

64. Back slope must be 2:1 or flatter.

Material

65. The level spreader must be constructed in undisturbed soil and must outlet onto an area stabilized with vegetation.

Outlet

66. Final discharge will be over the level lip protected with fiberglass matting, erosion stops, and jute or excelsior protective material onto an existing stabilized area. Vegetative cover should be used to stabilize the

area enough to resist erosion. The level lip should be of uniform height and zero grade over the length of the spreader.

Maintenance

67. The measure should be inspected after every rainfall and repairs made if required. The contractor should avoid the placement of any material on and prevent construction traffic across the structure. If the measure is damaged by construction traffic, it must be repaired immediately.

OUTLET PROTECTION

68. Outlet protection (Figure D-19) is the providing of energy dissipation devices and erosion-resistant channel sections between drainage outlets and stable existing downstream channels. The channel sections may be rock lined, vegetated, paved with concrete, or otherwise made erosion resistant. The purpose of outlet protection is to prevent scour around pipe outlets.

Figure D-19. Outlet protection

69. The most commonly used device for outlet protection is a structurally lined apron. These aprons are generally lined with riprap, grouted riprap, or concrete. They are constructed at a zero grade for a distance which is related to the outlet flow rate and the tailwater level.

Design Criteria

70. A plan view, profile, and cross section of each channel reach between the storm drain outlet and the receiving natural stream channel are required. Velocities should be indicated at the following: (a) outlet (pipe, structure, or paved channels), (b) riprap or paved apron section, and (c) each successive channel reach from the end of the apron to the point of entry into the existing natural stream. The proposed method of stabilizing each channel reach, consistent with computed velocities, should be shown on the plan. The velocity at the end of a structure or channel reach must not exceed the allowable velocity for the next downstream reach.

71. A channel reach is defined as a length of channel throughout which the hydraulic characteristics do not change. These characteristics include

channel depth of flow, roughness, channel gradient, side slopes, bottom width, discharge rate, and velocity. A natural stream channel is defined as a naturally formed channel through which the storm runoff would have flowed (had there been no intervention by man) and which is capable of conveying the peak rate of runoff after development without eroding.

Applicability

72. This practice applies to storm drain outlets, road culverts, paved channel outlets, etc., where a large erosion potential exists. Analysis and appropriate treatment should be provided along the entire length of the flow path from the end of the conduit, channel, or structure to the point of entry into an existing stream or publicly maintained drainage system. This is especially important if the velocity of flow at the design capacity of the outlet will exceed the permissible velocity of the receiving channel or area.

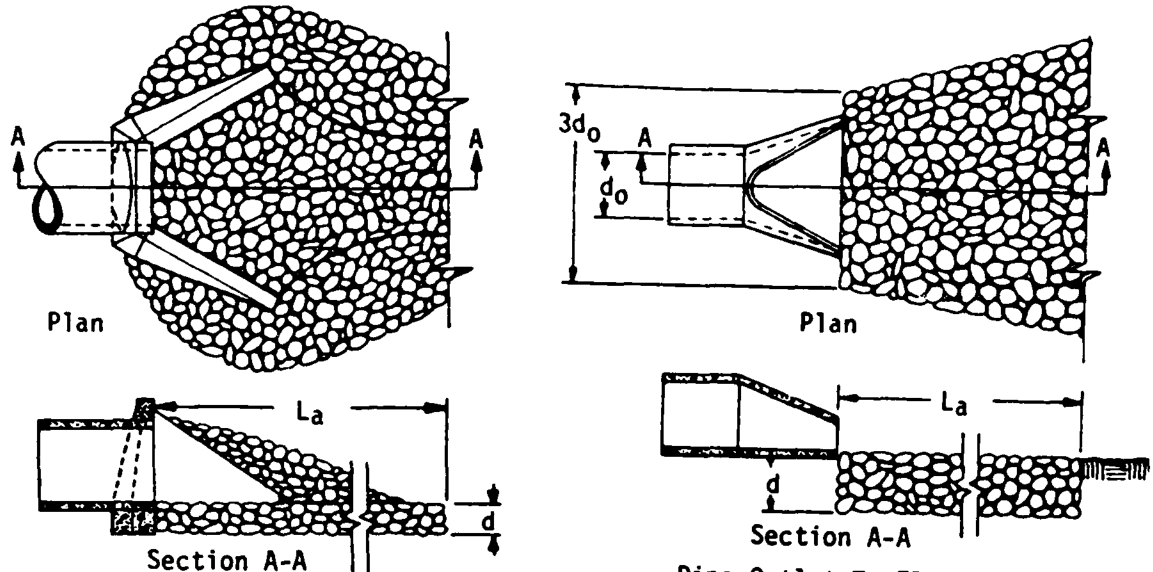
Planning Considerations

73. Stormwater which is transported through man-made conveyance systems at design capacity generally reaches a velocity which exceeds the limiting velocity of the receiving channel. This may result in scour of the stormwater outlet. To prevent scour, a flow transition structure is needed which will absorb the initial impact of the flow and reduce the flow velocity to a level which will not erode the receiving channel or area.

Pipe Outlets

74. Each pipe outlet should have a structurally lined apron or other suitable energy dissipating structure immediately downstream from the outlet (Figure D-20). The structurally lined apron should meet the following criteria:

a. Tailwater depth. The depth of tailwater immediately below the pipe outlet must be determined for the design capacity of the pipe. Manning's equation may be used to determine tailwater depth. A minimum tailwater condition is achieved when the tailwater depth is less than half the diameter of the outlet pipe. A maximum tailwater condition is achieved when the tailwater depth is greater than half the pipe diameter. Pipes which



Pipe Outlet To Well-Defined Channel

Pipe Outlet To Flat Area With No Defined Channel

d = 2.0 times the maximum stone diameter but not less than 6 inches.

Construction Specifications

1. For natural or vegetated channels, see Waterways.
2. Aprons at the end of pipe or lined channel outlets should meet the following criteria:
   a. Bottom grade should be 0.0 percent.
   b. Side slopes should be 2:1 or flatter.
   c. Sidewalls should extend as shown on the plans but not less than two-thirds the pipe diameter.
   d. There should be no overfall from the end of the apron to the surface of the receiving channel. The area to be paved or riprapped should be undercut so that the invert of the apron is at the same grade (flush) with the surface of the receiving channel. The apron should have a cut-off or toe wall at the downstream end.
   e. Apron dimensions and riprap size or concrete thickness should be as shown on the plans.
   f. The width of the end of the apron should be equal to the bottom width of the receiving channel.
   g. Do not place fill, either loose or compacted, in the receiving channel.
   h. No bends or curves in the horizontal alignment of the apron will be permitted.
3. Riprap construction should comply with the requirements for Riprap.

Figure D-20. Pipe outlet conditions (VSWCC 1980)

outlet onto flat area with no defined channel are assumed to have a minimum tailwater condition.

b. Apron length. The apron length is determined by the tailwater condition using the curves shown in Figures D-21 and D-22.

c. Apron width. When the pipe discharges directly into a well-defined channel, the apron should extend across the channel bottom and up the channel banks to an elevation 1 ft above the maximum tailwater depth or to the top of the bank (whichever is less), but no lower than two thirds of the vertical conduit dimension above the conduit invert. If the pipe discharges onto a float area with no defined channel, the width of the apron is determined as follows:

(1) The upstream end of the apron, adjacent to the pipe, should have a width three times the diameter of the outlet pipe.

(2) For a minimum tailwater condition, the downstream end of the apron will have a width equal to the pipe diameter plus the length of the apron. $W = \text{diameter} + L_a$.

(3) For a maximum tailwater condition, the downstream will have a width equal to the pipe diameter plus 0.4 times the length of the apron. $W = \text{diameter} + 0.4\ L_a$.

d. Bottom grade. The apron should have no slope along its length (0.0 percent grade).

e. Side slopes. If the pipe discharges into a well-defined channel, the side slopes of the channel should not be steeper than 2:1 (horizontal:vertical).

f. Invert elevation. Invert elevation at the end should be equal to, or lower than, the lowest elevation on the cross section immediately downstream from the end of the apron (i.e., no overfall at the end of the apron).

g. Materials. Size of riprap and length of apron should be determined and riprap should meet the requirements for Riprap. Concrete paving may be substituted for the riprap. The gradation, quality, and placement of riprap should conform to Riprap.

h. Alignment. There should be no bends or curves in the horizontal alignment of the pipe and the apron unless the structure is designed to adequately handle the flow.

Paved Channel Outlets

75. The following criteria should be followed for paved channel sections (see Figure D-23):

a. Velocity at the end of the paved section should be less than the allowable velocity for the succeeding downstream section.

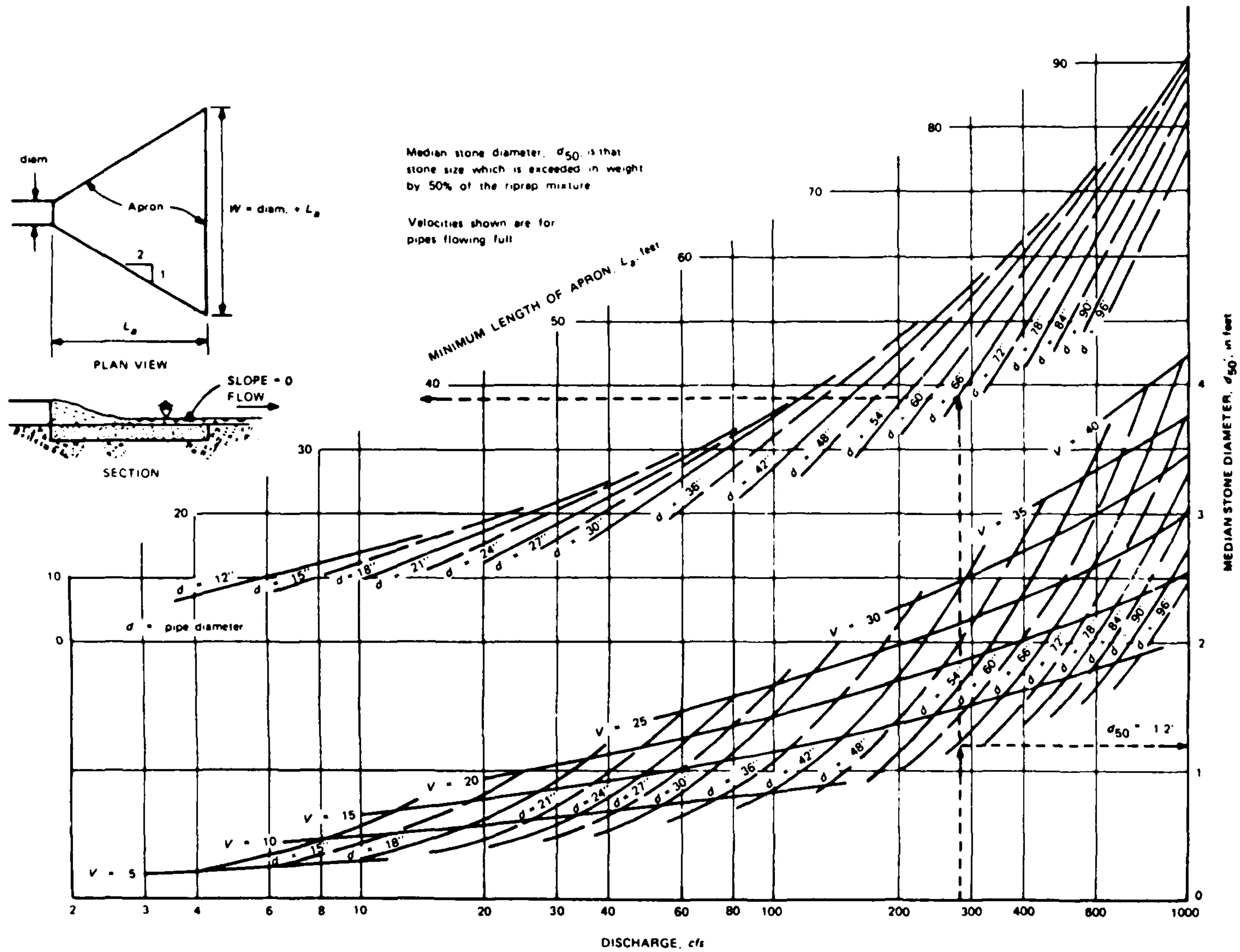


Figure D-21. Design or outlet protection - minimum tailwater condition (T_W < 0.5 diameter) (USDA, SCS 1975)

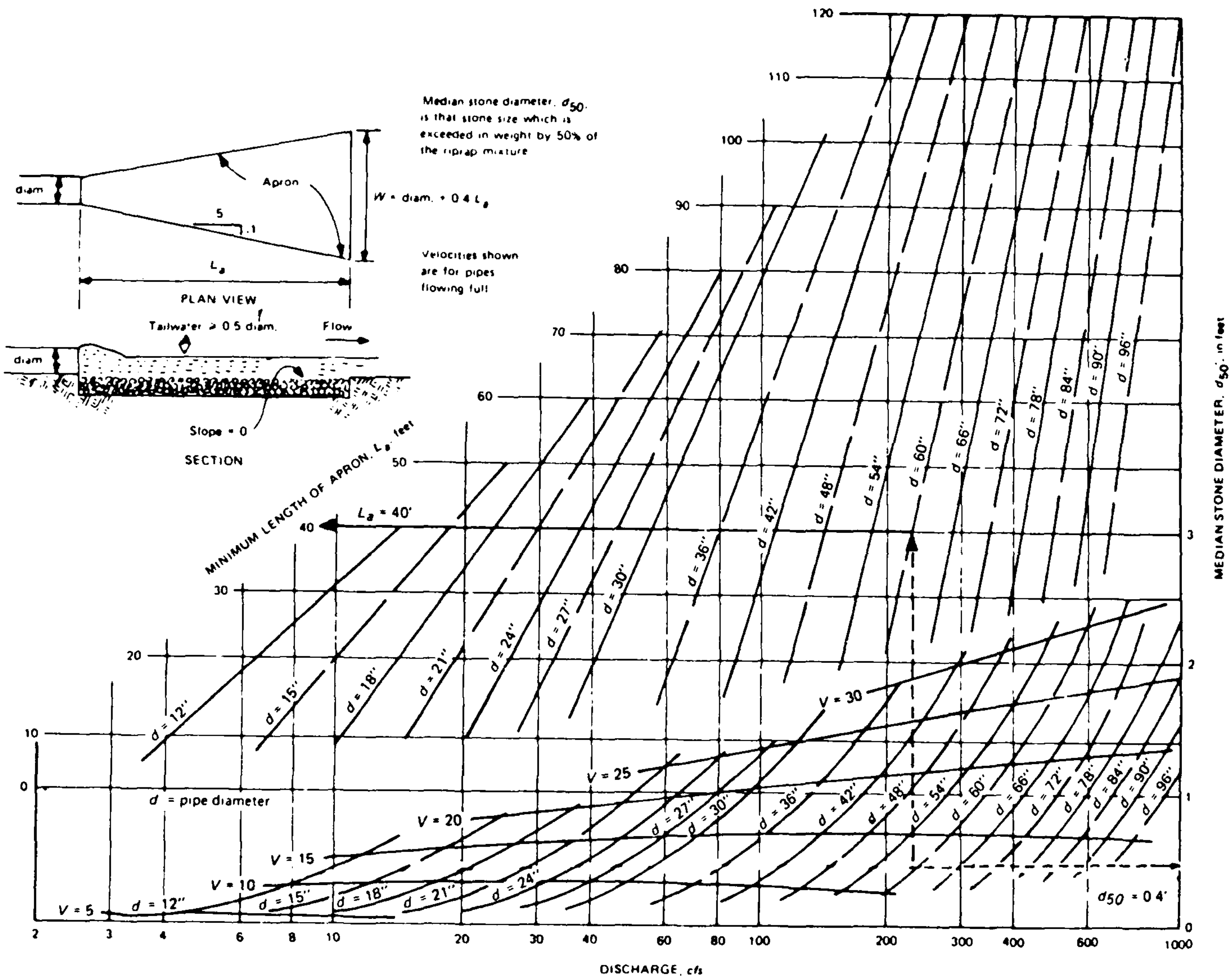
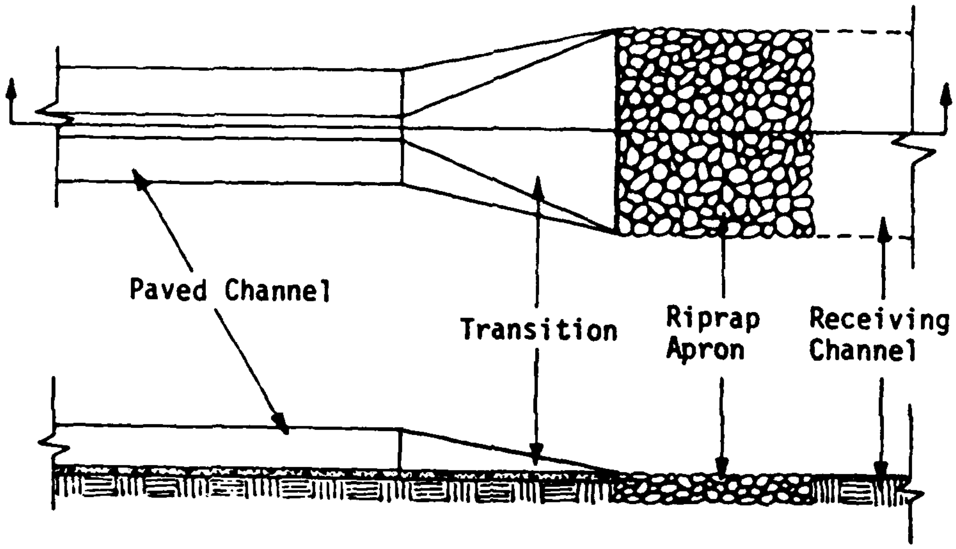


Figure D-22. Design of outlet protection - maximum tailwater condition ($T_W \geq 0.5$ diameter) (USDA, SCS 1975)



Construction Specifications

1. For natural or vegetated channels, see Grassed Waterways.

   a. Side slopes, dimensions, grades, etc., should be as shown on the plans.
   b. There should be no overfall from the end of the paving to the surface of the receiving channel.
   c. Riprap size or concrete thickness, joint details, etc. should be as shown on the plans.
   d. The end of the paved sections should be as wide as the receiving channel and the transition between the two channels should be smooth.
   e. The placing of fill (either loose or compacted) in the receiving channel should not be allowed.
   f. Bends or curves in the horizontal alignment of paved channels are not acceptable unless shown on the plans, and the radius of curvature must be the same as shown on the plans.

2. Riprap construction should comply with the requirements for Riprap.

Figure D-23. Paved channel outlet (VSWCC 1980)

b. The downstream end of the invert of the paved section should be no higher than the lowest point in the channel immediately downstream from the end of the paved section (i.e., no overfall at the end of the apron).

c. The end of a paved channel should merge smoothly with the next downstream channel section. This transition must be accomplished within the paved channel. The bottom width of the end of the paved channel should be at least as wide as the bottom width of the downstream channel. The maximum side divergence of a transition should be 1 in 3F , where the Froude number is given by $F = V \sqrt{gd}$, where V = the velocity, d = the depth of flow at the beginning of the transition, and g = acceleration due to gravity, 32.2 ft/sec^2.

d. Bends or curves in the horizontal alignment of paved channels are not acceptable unless the Froude number, F , is 0.8 or less or the channel is specifically designed to contain the turbulent flow.

Channel Velocity in Unpaved Channels

76. Each channel reach having a natural, vegetated, or riprap-paved bottom should be checked for stability by calculating the flow velocity using Manning's equation and then ensuring that the channel will handle that velocity without eroding. Field surveys will be necessary to determine cross sections, grades, types of material in the channel, and condition of the channel.

Channel Design Data

77. The roughness coefficient, n , is as follows (Chow 1959):

Channel Lining	n Value
Metal	
a. Smooth steel surface	
(1) Unpainted	0.012
(2) Painted	0.013
b. Corrugated	0.025
Nonmetal	
a. Cement	
(1) Neat, surface	0.011
(2) Mortar	0.013
b. Wood	

Channel Lining	n Value
(1) Planed, untreated	0.012
(2) Planed, creosoted	0.012
(3) Unplaned	0.013
(4) Plank with battens	0.015
(5) Lined with roofing paper	0.014
c. Concrete	
(1) Trowel finish	0.013
(2) Float finish	0.015
(3) Finished, with gravel on bottom	0.017
(4) Unfinished	0.017
(5) Gunite, good section	0.019
(6) Gunite, wavy section	0.022
(7) On good excavated rock	0.020
(8) On irregular excavated rock	0.027
d. Concrete bottom float finished with sides of	
(1) Dressed stone in mortar	0.017
(2) Random stone in mortar	0.020
(3) Cement rubble masonry, plastered	0.020
(4) Cement rubble masonry	0.025
(5) Dry rubble or riprap	0.030
e. Gravel bottom with sides of	
(1) Formed concrete	0.020
(2) Random stone in mortar	0.023
(3) Dry rubble or riprap	0.033
f. Brick	
(1) Formed concrete	0.013
(2) In cement mortar	0.015
g. Masonry	
(1) Cemented rubble	0.025
(2) Dry rubble	0.032
(3) Dressed ashlar	0.015
h. Asphaltic concrete	
(1) Machine finished	0.018
(2) Hand finished	0.022
i. Natural channels not completely lined with vegetation	0.025
j. Gabion mattesses	0.028
k. Fabriform® - Filter point (waffled surface)	0.025
l. Riprap	See Riprap
m. Vegetation	See Grassed Waterways

f. Determine the safety factor of the design and ensure that it is greater than 1. This is given by:

$$SF = \frac{\cos R \tan d}{n' \tan d + \sin R \cos b}$$

where

- R is the side slope angle
- d is the angle of repose
- b is the angle indicating particle movement
- n' is the stability number for particles on embankment side slopes

n' is given by:

$$n' = n \left[\frac{1 + \sin (S + B)}{2}\right]$$

where

- S is the dip angle of the channel
- n is the stability number for particles on plane surfaces

n is given by:

$$n = \frac{0.30V^2}{(S_s - 1)\ gK}$$

where

- V is the velocity of flow in the channel
- S_s is the specific gravity of the individual stones
- g is the acceleration constant
- K is the size of the riprap stone

b is given by:

$$b = \tan^{-1} \left(\frac{\cos S}{\frac{2 \sin R}{n \tan d} + \sin S}\right)$$

Triangular channels

a. From Figure D-30, using S_b , Q , and z , find the median riprap diameter, d_{50} , for straight channels.

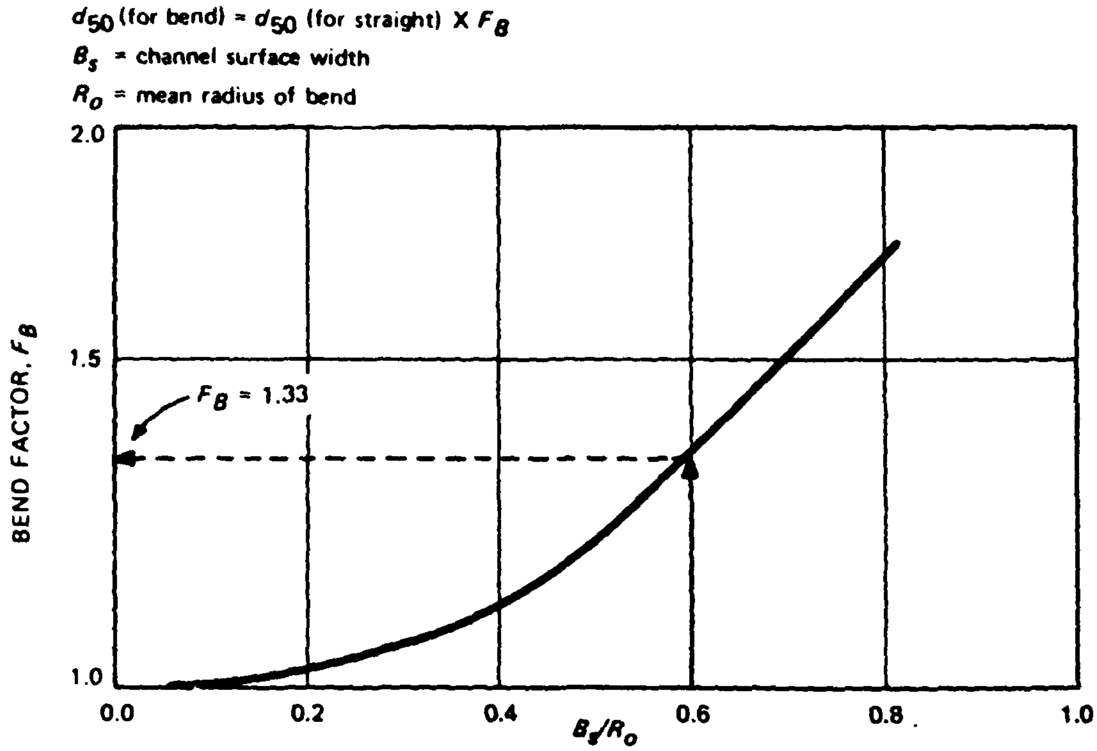


Figure D-28. Riprap size correction factor for flow in channel bends (USEPA 1976)

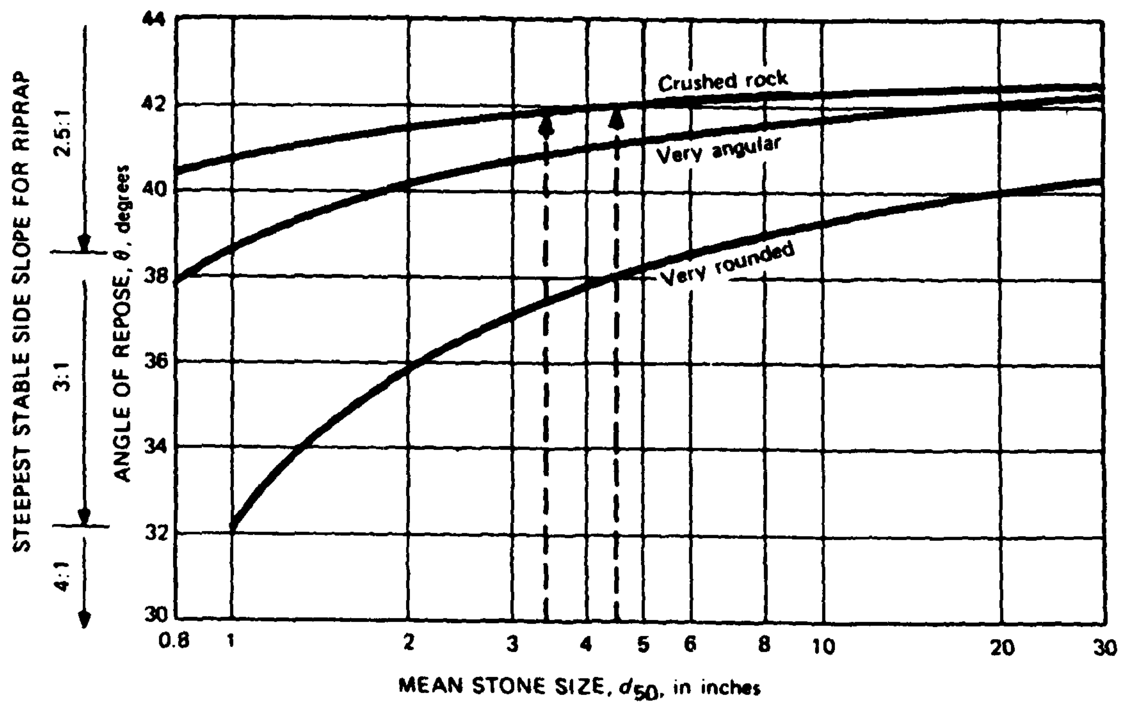


Figure D-29. Maximum riprap side slope with respect to riprap size (USEPA 1976)

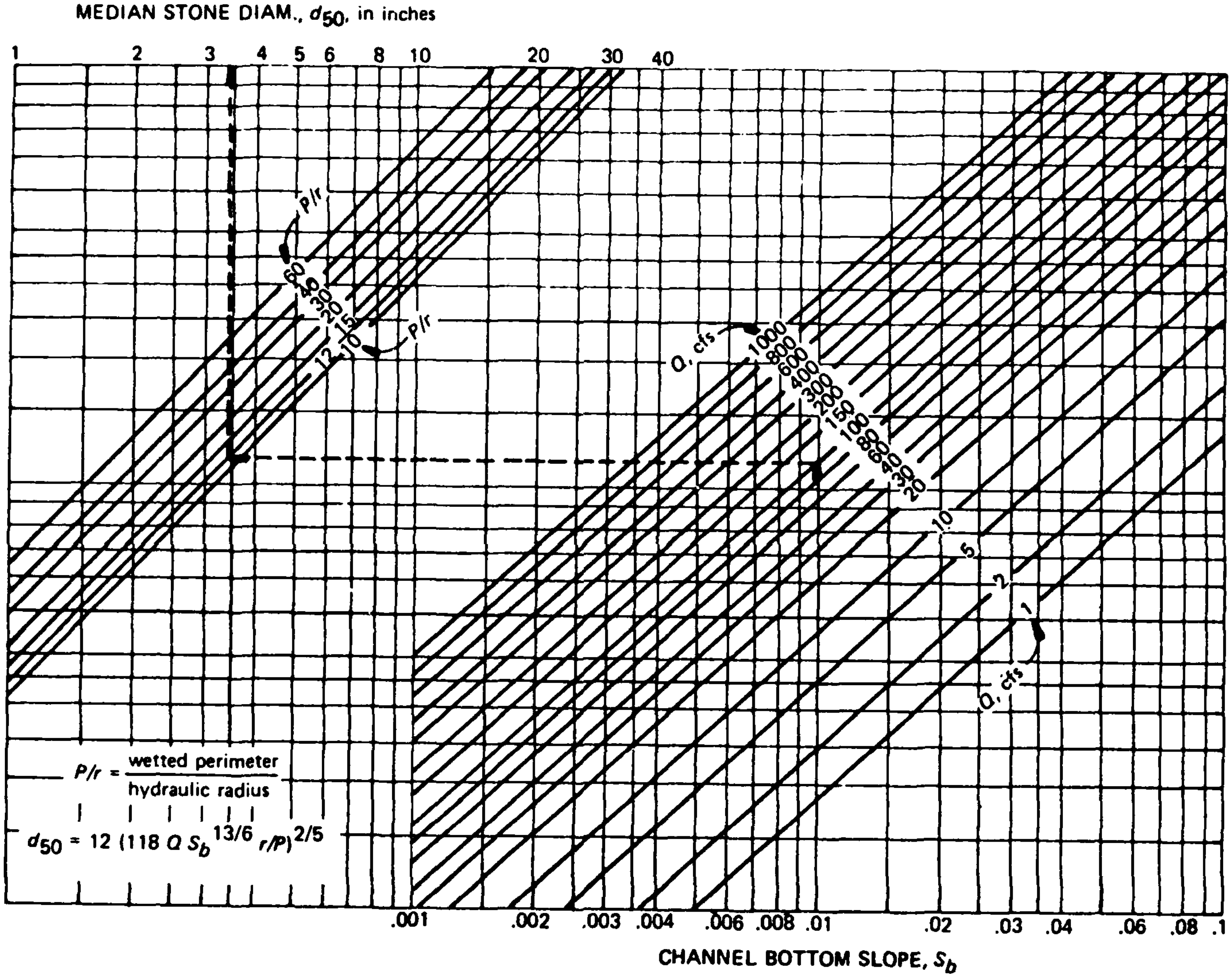


Figure D-27. Median riprap diameter for straight trapezoidal channels (USEPA 1976)

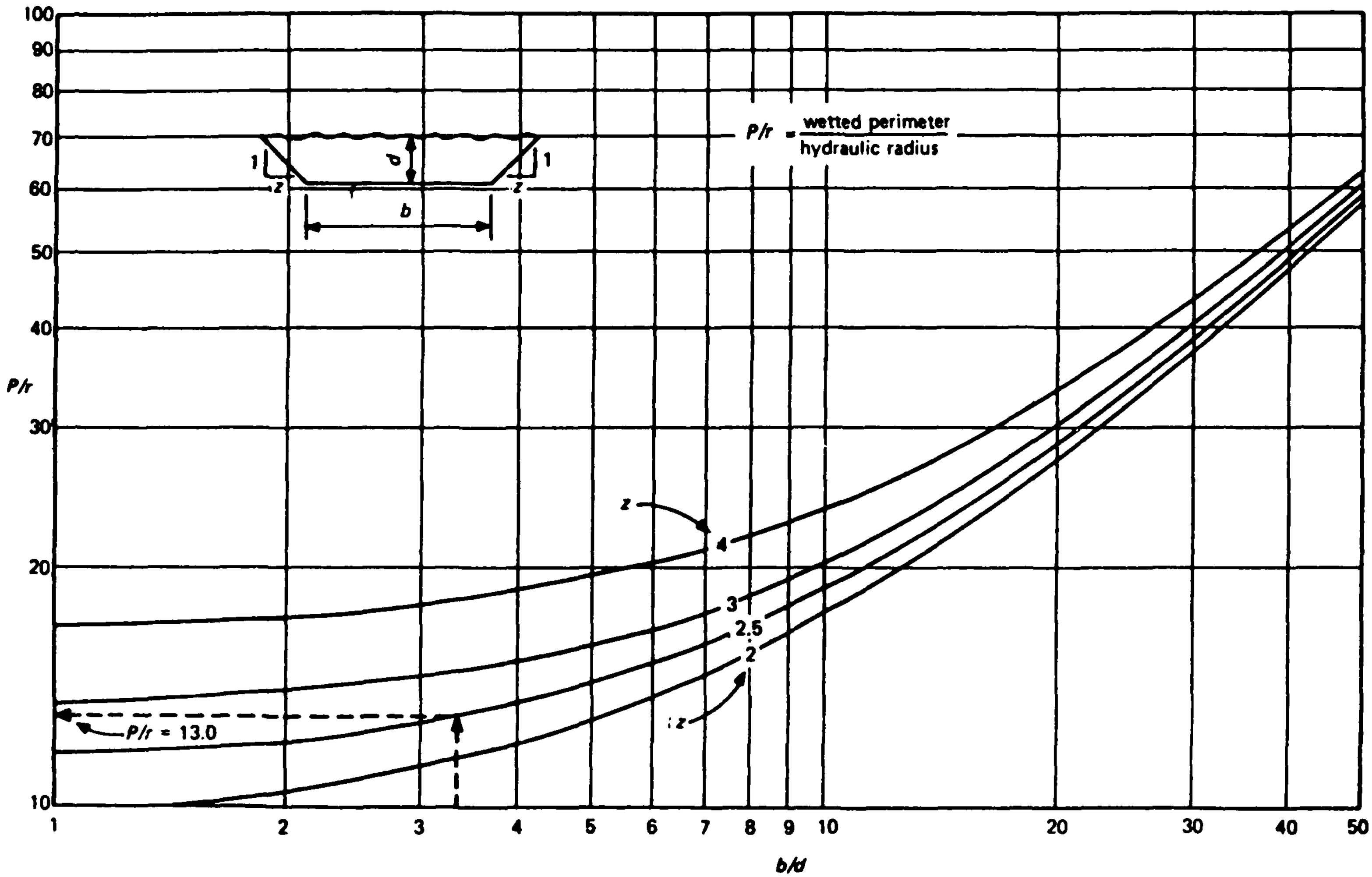


Figure D-26. P/r for trapezoidal channels (USEPA 1976)

109. The report cited above gives a simple and direct solution to the design of trapezoidal channels including channel carrying capacity, channel geometry, and riprap lining. The publication is a very good reference and design aid.

110. The procedure presented in this section is based on the assumption that the channel is already designed and the remaining problem is to determine the riprap size that would be stable in the channel. The designer would first determine the channel dimensions by the use of Manning's equation. The n value in Manning's equation is derived by estimating a riprap size and then determining the corresponding n value for the riprapped channel from Figure D-25.

111. When the channel dimensions are known, the riprap can be designed (or an already completed design may be checked) as follows:

Trapezoidal channels

a. Calculate the b/d ratio and find the P/r ratio in Figure D-26.

b. From Figure D-27, using S_b, Q, and P/r, find the median riprap diameter, d_{50}, for straight channels.

c. In Figure D-25, find the actual n value corresponding to the d_{50} from step 2. If the estimated and actual n values are not in reasonable agreement, another trial must be made.

d. For channels with bends, calculate the ratio B_s/R_o, where B_s is the channel surfaced width and R_o is the radius of the bend. Use Figure D-28 to find the bend factor, F_B. Multiply the d_{50} for straight channels by the bend factor to determine riprap size to be used in bends. If the d_{50} for the bend is less than 1.1 times the d_{50} for the straight channel, then the size for the straight channel may be used in the bend; otherwise, the larger stone size calculated for the bend should be used. Riprap must extend across the full channel section and must extend upstream and downstream from the ends of the curve a distance equal to five times the bottom width.

e. From Figure D-29, determine the maximum stable side slope of riprap surface.

b. For filter cloth adjacent to all other soils: EOS less than US Standard Sieve No. 70. Total open area of filter is less than 10 percent. No filter cloth should be used with less than 4 percent open area or an EOS less than US Standard Sieve No. 100.

105. Filter blankets should always be provided where seepage from underground sources threatens the stability of the riprap. Filter blankets are not required with riprap used for storm drain outlet protection. In addition, riprap 12 in. and larger may tear or displace the filter cloth when directly dumped onto the plastic filter cloth. Instead, a 4-in. minimum thickness blanket of gravel should be placed directly on the filter cloth by hand or by the bucket of the equipment. Side slopes should be 2:1 or flatter to prevent the gravel from sliding down the filter cloth before placing the riprap.

Design Procedures

Riprap at outlets

106. Design criteria for sizing the stone and determining the dimensions of riprap pads used at the outlet of drainage structures are included under Outlet Protection.

Riprap for channel stabilization

107. The design of riprap-lined channels (National Research Council, Highway Research Board 1970) is based on the tractive force method and covers the design of riprap in two basic channel shapes: trapezoidal and triangular.

108. When designing riprap-lined channels, these points should be kept in mind:

a. The riprap should extend up the banks to a height above the maximum depth of flow or to a point where vegetation can be established to adequately protect the channel.

b. The riprap size used in a bend should extend upstream from the point of curvature, and downstream from the point of tangency a distance equal to five times the channel bottom width (length = five bottom widths). This riprap size should extend across the bottom and up both sides of the channel.

c. In channels with no riprap or paving in the bottom, the toe of the bank riprap should extend below the channel bottom a distance at least 1.5 times the maximum stone size, but no less than 1 ft. The only exception would be where there is a nonerodible hard rock bottom. The channel bank should not be steeper than 2.0 horizontal to 1.0 vertical.

101. A filter has two general forms. One is a single layer of plastic filter cloth manufactured for that express purpose. Another is a properly graded layer of sand, gravel, or stone.

102. Gravel filter blanket. The following relationships must exist:

$$\frac{d_{15}\ \text{filter}}{d_{85}\ \text{base}} \leq 5 \quad < \quad \frac{d_{15}\ \text{filter}}{d_{15}\ \text{base}} < 40$$

and

$$\frac{d_{50}\ \text{filter}}{d_{50}\ \text{base}} < 40 \quad < \quad \frac{d_{15}\ \text{riprap}}{d_{85}\ \text{base}} \leq 5$$

in which d_{15}, d_{50}, or d_{85} is the size of base, filter, or riprap material. In these equations, 15, 50, and 85 percent, respectively, are finer. The base is the soil layer underneath the filter. The filter must be graded down to sand-size particles.

103. In these relationships, the overlying material is referred to as the filler while the underlying material is referred to as the base. The relationships must hold between the filter material and the base material and between the riprap and the filter material. In some cases, more than one layer of filter material may be needed. Each layer of filter material should be a minimum of 6 in. thick and large enough to accommodate the maximum size rock.

104. Plastic filter cloth. A plastic filter cloth may be used in place of or in conjunction with gravel filters. The following particle size relationships must exist:

a. For filter cloth adjacent to granular materials containing 50 percent or less (by weight) of fine particles (less than 0.074 mm):

$$\frac{d_{85}\ \text{base (mm)}}{\text{EOS* filter cloth (mm)}} < 1$$

Total open area of filter is less than 36 percent.

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* EOS = equivalent opening size to a US standard sieve size.

Gradation

94. The riprap should be composed of a well-graded mixture down to the 1-in. size particle, such that 50 percent of the mixture by weight shall be larger than the d_{50} size. A well-graded mixture is defined as a mixture composed primarily of the larger stone sizes, but with a sufficient mixture of other sizes to fill the progressively smaller voids between the stones. The diameter of the largest stone size in such a mixture is considered to be two times the d_{50} size. The riprap size as shown on the plans and specifications or for other construction purposes should be the size of the largest stone in the mixture, i.e., $2 \times d_{50}$.

95. The riprap size determined to be stable under the flow conditions is considered to be the minimum size. The designer will then, based on riprap graduations actually available in the area, select the size or sizes that equal or exceed the minimum size.

Thickness

96. The minimum thickness in the riprap layer should be two times the maximum stone diameter but not less than 6 in.

Quality

97. Riprap stone should consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone should be hard and angular and should not disintegrate on exposure to water or weathering. The stone should be suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

98. Rubble concrete meeting the requirements already specified and having a density of at least 150 lb/ft^3 may also be used.

Filter blankets

99. A filter blanket is a layer of material placed between the riprap and the underlying soil surface to prevent soil movement into or through the riprap.

100. A filter should be placed under riprap whenever any of the following conditions exist:

- a. The riprap is not well graded down to the 1-in. size particle.
- b. Riprap is placed on the side slopes of a channel and the soil is sand size or finer with a plasticity index, PI, less than 10. This requirement applies to slopes having this soil in lenses or layers greater than 3 in. in thickness.

Design Criteria

91. The minimum design discharge for channels and ditches should be the peak discharge from the design storm, based on maximum watershed disturbance during the life of the structure. A 2-year, 24-hr duration storm will be used for design of permanent structures. The roughness coefficient, n , used for determining flow on the constructed riprap surface, is as shown in Figure D-25.

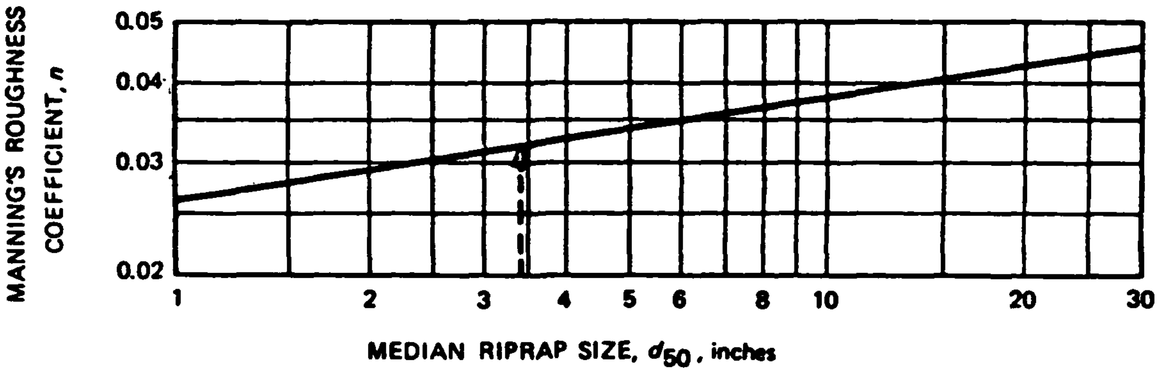


Figure D-25. Manning's n for riprap-lined channels

92. In the design of riprap-lined channels, "Tentative Design Procedure for Riprap-Lined Channels" (National Research Council, Highway Research Board 1970) details the procedure for determining a design stone size such that the stone is stable under the design flow conditions with a reasonable factor of safety. The design stone size used is the d_{50} , or median stone diameter, defined as that stone size which is exceeded in weight by 50 percent of the mixture.

93. Erosive forces of flowing water are greater in bends than in straight channels. Therefore, riprap size for bends and straights in the channel must be computed. If the riprap size (d_{50}) computed for bends is less than 10 percent greater than the riprap size for straight channels, then the riprap size for straight channels is considered to be adequate; otherwise, the larger riprap size is used in the bend. This is done to minimize the number of riprap sizes required. No more than two riprap sizes should be used on any single contract, in order to minimize construction problems caused by too many sizes.

required. For example, d_{85} refers to a mixture of stones in which 85 percent of the stone by weight would be smaller than the diameter specified. Most designs are based on d_{50}. In other words, the design is based on the average size of stone in the mixture. Table D-5 lists Virginia Department of Highways and Transportation standard graded riprap sizes by diameter and weight of the stone.

Table D-5

Graded Riprap

Riprap Class	D_{15} Weighted, lb	Mean D_{15} Spherical Diameter, ft	Mean D_{50} Spherical Diameter, ft
Class I	50	0.8	1.1
Class II	150	1.3	1.6
Class III	500	1.9	2.2
Type I	1500	2.6	2.8
Type II	6000	4.0	4.5

89. Colorado State studies involving riprap sizes are also presented. The studies have shown that the following gradation is superior (Simons and Senturk 1977):

Percent Finer	Size in Fraction of D_{50}
100	2.0
50	1.0
20	0.5
0	0.2

Sequence of construction

90. Construction must be sequenced so that the riprap must be put in place with the least possible delay since it is used where erosion potential is high. Disturb areas to be riprapped only when final preparation and placement of riprap can follow immediately behind the initial disturbance. Where riprap is used for outlet protection, the riprap should be placed before or in conjunction with the construction of the pipe or channel so that it is in place when the pipe or channel begins to operate.

86. Graded riprap is generally preferred to uniform riprap. Graded riprap forms a flexible self-healing cover, while uniform riprap is more rigid and cannot withstand movement of the stones. Graded riprap is cheaper to install, requiring only that the stones be end dumped so that they remain in a well-graded mass. Uniform riprap requires placement in a more or less uniform pattern, requiring more hand or mechanical labor than graded riprap where placement is limited to that necessary to achieve the proper thickness and line.

87. Riprap sizes can be designated by either the diameter or the weight of the stones. It is often misleading to think of riprap in terms of diameter since the stones should be rectangular instead of spherical. However, it is simpler to specify the diameter of an equivalent size of spherical stone. Table D-4 lists some typical stones by weight, spherical diameter, and the corresponding rectangular dimensions. These stone sizes are based upon an assumed specific weight of 165 lb/ft^3 (specific gravity of 2.65).

Table D-4

Size of Riprap Stones (VSWCC 1980)

Weight, lb	Mean Spherical Diameter, ft	Rectangular Shape: Length, ft	Rectangular Shape: Width, Height, ft
50	0.8	1.4	0.5
100	1.1	1.75	0.6
150	1.3	2.0	0.67
300	1.6	2.6	0.9
500	1.9	3.0	1.0
1,000	2.2	3.7	1.25
1,500	2.6	4.7	1.5
2,000	2.75	5.4	1.8
4,000	3.6	6.0	2.0
6,000	4.0	6.9	2.3
8,000	4.5	7.6	2.5
20,000	6.1	10.0	3.3

88. In order to specify the size range of the grade riprap, a diameter of stone in the mixture for which some percentage, by weight, is smaller is

RIPRAP

83. Riprap (Figure D-24) is a permanent layer of large, loose, angular rock or aggregate placed over an erodible soil surface. The purpose of riprap is to protect the soil surface from the erosive forces of water, to slow the velocity of concentrated runoff thereby increasing the infiltration potential, to stabilize slopes with seepage problems, and to stabilize noncohesive soils.

Figure D-24. Riprap

Applicability

84. Riprap is used where the soil conditions, water turbulence and velocity, expected vegetative cover, and ground-water conditions are such that the soil may erode under the design flow conditions. Riprap may be used in such places as diversion channel banks and/or bottoms, roadside ditches, and drop structure outlets.

Planning Considerations

Riprap size

85. Riprap is classified as either graded or uniform. Graded riprap contains a mixture of stones which vary in size from small to large. Uniform riprap contains stones which are all fairly close in size.

80. The first step is to determine the tailwater condition, as discussed in Design Criteria. Then, for circular conduits, use the appropriate chart (Figure D-21 or D-22) and, based on the discharge and the pipe diameter, determine the riprap size and the apron length. Then calculate apron width and maximum stone size in the riprap mixture.

Example 1:

A circular conduit is flowing full.

Q = 280 cfs, diameter = 66 in., and tailwater (surface) is 2 ft above pipe invert.

This is a minimum tailwater condition (Figure D-21).

Therefore, $d_{50} = 1.2$ ft, and apron length, $L_a = 38$ ft.

Apron width, $W = \text{diameter} + L_a = 5.5 + 38 = 43.5$ ft.

Maximum stone size in the riprap mixture $= 2.0 \times d_{50} = 2.0 \times 1.2 = 2.4$ ft.

81. In the design of outlet protection for rectangular conduits, the depth of flow and velocity are used. Determine the tailwater condition and the appropriate chart (Figure D-21 or D-22). Use the lower set of curves and, based on the velocity V and depth (using the diameter curves for depth), determine d_{50} and the length of apron. To determine the apron width, substitute conduit width for diameter in the apron width equations.

Example 2:

A concrete box 5.5 ft × 10 ft is flowing 5.0 ft deep. Q = 600 cfs and the tailwater (surface) is 5 ft above invert. This is a maximum tailwater condition (Figure D-21).

$$V = \frac{Q}{a} = \frac{600}{5.0 \times 10} = 12 \text{ fps}$$

Therefore, $d_{50} = 0.4$ ft, and apron length, $L_a = 40$ ft.

Apron width, $W = \text{conduit width} + 0.04\ L_a = 10 + (0.4)$ (40) 26 ft.

Maximum stone size $= 2.0 \times d_{50} = 2.0 \times 0.4 = 0.8$ ft.

Maintenance

82. Once the riprap installation has been completed, it should require very little maintenance. It should, however, be inspected periodically to determine if high flows have caused scour beneath the riprap or dislodged any of the stone. If repairs are needed, they should be accomplished immediately.

78. Maximum flow velocities are as follows (Fortier and Scobey 1926; USDA, SCS 1979b):

Channel Lining	Maximum Velocity fps: Clear Water	Maximum Velocity fps: Water Transporting Colloidal Silt
a. Natural channels not completely lined with vegetation		
(1) Sand and sandy loam	1.50	2.5
(2) Silt loam	2.00	3.0
(3) Sandy clay loam	2.00	3.5
(4) Clay loam	3.00	4.0
(5) Clay, fine gravel, and graded loam to gravel	3.75	5.0
(6) Graded silt to cobbles	4.00	5.5
(7) Shale, hardpan, and coarse gravels	6.00	6.0
b. Riprap		See Riprap
c. Vegetation		See Grassed Waterways

Design Procedures

79. Outlet protection is a method which causes the expanding flow (from pipe or conduit to channel) to lose velocity and energy such that it will not erode the next downstream channel reach. This protection is usually provided by a level apron which is designed based on curves developed for circular conduits flowing full. The curves provide the apron size and the minimum d_{50} size for riprap. There are two curves, one for a low or minimum tailwater condition (Figure D-21) and one for a high or maximum tailwater condition (Figure D-22). The minimum condition applies to a tailwater surface elevation less than the center of the pipe, whereas the maximum condition applies to a tailwater surface elevation equal to, or higher than, the center of the pipe.

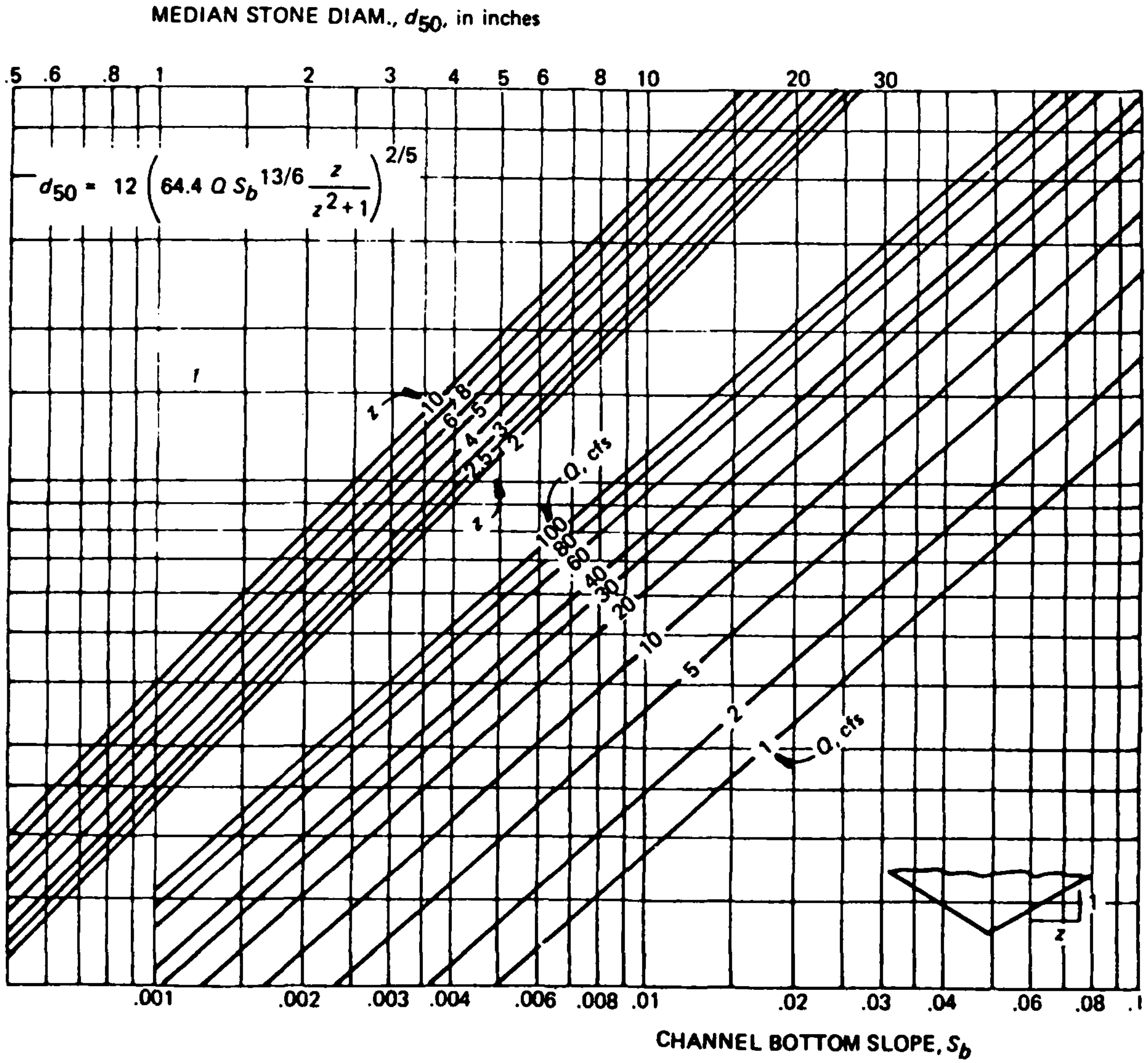


Figure D-30. Median riprap diameter for straight triangular channels (USEPA 1976)

b. From Figure D-25, find the actual n value. If the estimated and actual n values are not in reasonable agreement, another trial must be made.

c. For channels with bends, see step d under Trapezoidal Channels.

d. For safety factor calculation, see Trapezoidal Channels.

112. The riprap size to be specified on the plans is the maximum stone size in the mixture which is 2.0 times the d_{50}. The thickness of the riprap layer is 2.0 times the maximum stone size, but not less than 6 in. Freeboard is added to the channel depth and should not be less than 0.2 times the depth of flow, or 0.3 ft, whichever is greater.

Example:

Given: Trapezoidal channel

$Q = 100$ cfs
$S = 0.01$ ft/ft
Side slopes 2.5:1, $\theta = 22°$
Mean bend radius, $R_o = 25$ ft
$n = 0.033$ (estimated and used to design the channel to find that $b = 6$ ft and $d = 1.8$ ft)
Type of rock available is crushed stone

Solution:

Straight channel reach

$b/d = 6/1.8 = 3.3$
From Figure D-26, $P/r = 13.0$
From Figure D-27, $d_{50} = 3.4$ in.
From Figure D-25, n (actual) = 0.032, which is reasonably close to the estimate n of 0.033
Maximum riprap size = 2.0 × 3.4 = 6.8 in.
Riprap thickness = 2.0 × 5.1 = 10.2 in.
Use 7 in. as maximum riprap size and 10 in. as riprap layer thickness.

Channel bend

$B_s = b + 2zd = 6 + (2)(2.5)(1.8) = 15$ ft
$B_s/R_o = 15/25 = 0.60$
From Figure D-28, $F_B = 1.33$
$F_B = 1.33 > 1.1$; therefore, the bend factor must be used.
Riprap size in bend, $d_{50} = 3.4 \times 1.33 = 4.52$ in.
Maximum riprap size in bend = 4.52 × 2.0 = 9.04 in.
Riprap thickness = 6.78 × 2.0 = 13.56 in.
Use 9 in. for maximum riprap size and 13 in. for riprap layer thickness.

The heavier riprap for the bend shall extend upstream and downstream from the ends of the bend a distance of (5)(6) = 30 ft.

The riprap for d_{50} = 3.4 in. and 4.52 in., which will both be stable on a 2.5:1 side slope (Figure D-29).

Freeboard = (0.2)(1.8) = 0.36 ft which is not less than 0.3 ft. Therefore, minimum freeboard is 0.36 ft. Use 0.4 ft.

Safety factor

Area of channel = 1/2 (b + w) d

$w = b + 2\ (1.8/\tan 22°) = 15$ ft

$A = 1/2\ (6 + 15)\ 1.8 = 18.8\ \text{ft}^2$

$V = Q/A = 100\ \text{cfs}/18.8 = 5.31$ ft/sec

$$n = \frac{0.3\ (5.31)^2}{(2.65 - 1)(32.2)(0.58\ \text{ft})} = 2.75$$

$$b = \tan^{-1}\left[\frac{\cos 1°}{\frac{2 \sin 22}{0.275\ (\tan 35°)} + \sin 1°}\right] = 14.3$$

$$n' = 0.275\ \frac{[1 + \sin\ (1 + 14.3)]}{2} = 0.174$$

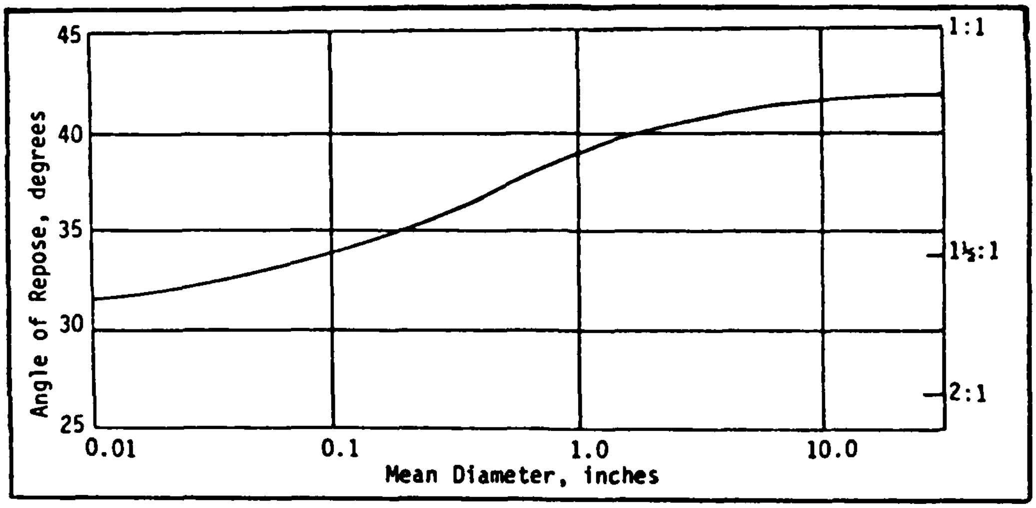
$$SF = \frac{\cos 22 \tan 35}{0.174\ (\tan 35) + \sin 22 \cos 14.3} = 1.34$$

Riprap for Slope Stabilization

113. Riprap for slope stabilization should be designed so that the natural angle of repose of the stone mixture is greater than the gradient of the slope being stabilized (Figure D-31).

Maintenance

114. Very little maintenance is required once a riprap installation has been completed. It should, however, be inspected periodically to determine if high flows have caused scour beneath the riprap or dislodged any of the stone. Repair any damage immediately.



Construction Specifications

1. Subgrade preparation. The subgrade for the riprap or filter must be prepared to the required lines and grades. Compact any fill required in the subgrade to a density approximating that of the surrounding undisturbed material. Remove all brush, trees, stumps, and other objectionable material.

2. Filter blanket. Filter blanket placement should be done immediately after slope preparation. The stone for granular filters should be spread in a uniform layer to the specified depth. Where more than one layer of filter material is used, the layers should be spread so that there is minimal mixing of the layers. Plastic filter cloths should be placed directly on the prepared slope, the edges of which should overlap by at least 12 inches. Space the anchor pins, 15 inches long, every 3 feet along the overlap. The upper and lower ends of the cloth should be buried a minimum of 12 inches deep. Take care not to damage the cloth when placing the riprap. Any damage other than an occasional small hole shall be repaired by placing another piece of cloth over the damaged part or by completely replacing the cloth. All overlaps, whether for repairs or for joining two pieces of cloth, should be a minimum of 1 foot. For large stone (12 inches or greater), a 4-inch layer of gravel may be necessary to prevent damage to the cloth.

3. Stone placement. Riprap should be placed immediately following the filter placement. Place the riprap so that it produces a dense, well-graded mass of stone with a minimum of voids. The desired distribution of stones throughout the mass may be obtained by selective loading at the quarry, controlled dumping of successive loads during final placing, or by a combination of these methods. Place the riprap to its full thickness in one operation. The riprap should not be placed in layers. Do not place the riprap by dumping into chutes or similar methods which are likely to cause segregation of the various stone sizes. Take care not to dislodge the underlying material or damage the filter blanket when placing the stones. The finished slope should be free of pockets or small stone or clusters of large stones. Hand placing may be necessary to achieve the required grades and a good distribution of stone sizes. The riprap blanket should have a final thickness within plus or minus 1/4 of the specified thickness.

Figure D-31. Angle of repose of riprap stones (VSWCC 1980)

SEDIMENT TRAPS

115. A sediment trap (Figure D-32) is a small, temporary basin formed by an excavation and/or an embankment to intercept sediment-laden runoff and to trap and retain the sediment long enough to allow the majority of the sediment to settle out. In so doing, drainageways, properties, and rights-of-way below the trap are protected from sedimentation.

Figure D-32. Sediment trap ready for cleaning (USEPA 1976)

Applicability

116. This practice has been recommended by the SCS (USDA, 1971) for use below drainage areas of 5 acres or less.* Larger areas should have sediment basins. These traps may be used at the foot of embankments where temporary and permanent slope drains discharge, at the lower end of waste areas or borrow pits, and at the downgrade end of a cut section where soil saturation will have no adverse effect. These traps should not be used where their expected lifetime is greater than 18 months.

117. Sediment traps should never be constructed in a streambed. The traps should be built outside an existing watercourse to minimize the quantity

* This recommendation was developed based on field experience in urbanizing areas in the humid eastern region and does not imply compliance with EPA effluent criteria.

of sediment to be trapped but as close as possible to the source of sediment. The traps may also be constructed either independently or in conjunction with a temporary diversion dike.

118. Sediment traps should not be used for removal of fine clay-size particles since this would require a much larger, more expensive structure. Most traps are designed to trap only sand-size and larger particles.

Planning Considerations

119. Planning of sediment traps should include the following considerations:

- a. Avoid construction of larger, more expensive traps. Use natural depressions and the existing topography for storage areas and treating the onsite runoff.
- b. Periodically remove sediment from the trap. Plans should detail how this is to be disposed of, such as in onsite fill areas or in offsite dumps.
- c. Install sediment traps before any land is disturbed in the drainage area.

Design Criteria

120. The design considerations for sediment basins should be consulted if any of the design criteria presented here cannot be met.

Drainage area

121. The maximum drainage area for a sediment trap is a function of the volume of runoff and sediment delivered to the trap as well as the grain-size distribution of the sediment. The (USDA, 1971) has recommended a maximum drainage area limitation of 5 acres for humid regions and thus this value would be expected to be higher for arid and semiarid regions.*

Location

122. The sediment trap should be located to obtain the maximum storage benefit from the terrain, to facilitate cleanout and disposal of trapped sediment, and to minimize interference with construction activities.

Trap size

123. The minimum volume of the trap can be calculated using standard

* This recommendation is not based on compliance with EPA effluent standards.

stage-area procedures. For a first estimate, the volume of a natural parabolic basin may be approximated by the formula:

$$\text{Volume (ft}^3\text{)} = 0.4 \times \text{surface area (ft}^2\text{)} \times \text{maximum depth (ft)}$$

For the humid eastern regions, the (USDA, 1971) recommends that the volume of a sediment trap as measured at the elevation of the crest of the outlet be at least 1800 ft^3 per acre of drainage area.

Trap cleanout

124. Sediment should be removed and the trap restored to its original dimensions when the sediment has accumulated to one half of the design depth of the trap. Sediment removed from the trap should be deposited in a suitable area and in such a manner that it will not erode. This is done to maintain an adequate detention volume for trapping sediment.

Embankment

125. All sediment trap embankments should not exceed 5 ft in height as measured at the low point of the original ground along the center line of the embankment. Embankments should have a minimum 4-ft-wide top and side slopes of 2:1 or flatter. The embankment should be compacted by traversing with equipment while it is being constructed.

Excavation

126. Carry out all excavation operations so that erosion and water pollution are minimized. Sediment traps should have excavated portions having 2:1 or flatter slopes.

Outlet

127. Sediment traps have three types of outlets: earth, pipe, and stone. Each sediment trap is named according to the type of outlet that it has. Each type has different design criteria and will be discussed separately. The outlets should be designed, constructed, and maintained in such a manner that sediment outflow from the trap is minimized and that erosion of the outlet does not occur. A trap may have several different outlets, each conveying part of the flow. For example, a 12-ft earth outlet (adequate for 2 acres) and a 12-in. pipe outlet (adequate for 1 acre) could be used for a 3-acre drainage area.

Removal

128. Sediment traps must be removed after the contributing drainage area is stabilized. Plans should show how the site of the sediment trap is to be graded and stabilized after removal.

Types of Traps

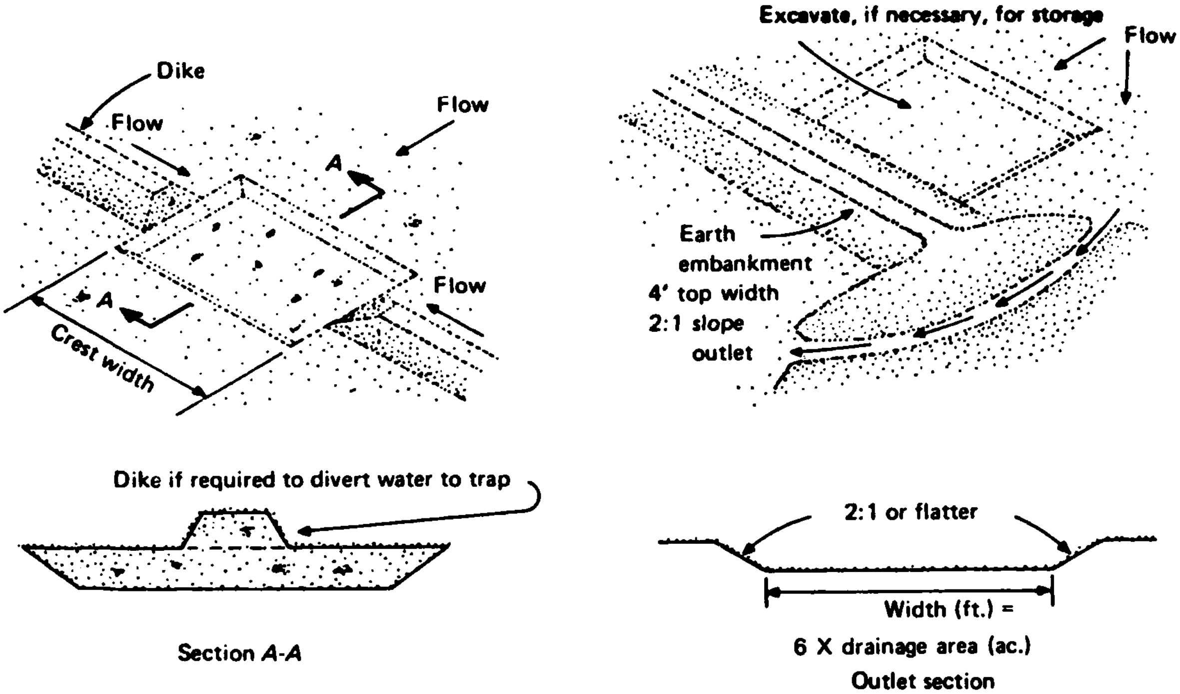
129. An earth outlet sediment trap (Figure D-33) consists of a basin formed by excavation and/or an embankment. The trap has a discharge point over or cut into natural ground. The outlet width (feet) should be designed so that erosion does not occur during the design storm. If an embankment is used, the outlet crest must be at least 1 ft below the top of the embankment with the outlet free of any restriction to flow. See Figure D-33 for details.

130. A pipe outlet sediment trap (Figure D-34) consists of a basin formed by an embankment or a combination of embankment and excavation. The outlet for the trap is through a perforated riser and a pipe through the embankment, both of which are made of corrugated metal. The riser diameter should be of the same or larger diameter than the pipe. The top of the embankment should be at least 1-1/2 ft above the crest of the riser. The pipe should be sized to pass the design storm. The pipe sizes will vary depending on the geographic region and the related volume of runoff. Table D-6 has been developed by the SCS for use in the humid eastern region.

131. Select pipe diameter from Table D-6. For details, see Figure D-34.

132. A stone outlet sediment trap (Figure D-35) consists of a basin formed by an embankment or a combination of an embankment and an excavation. The outlet for the trap is over a level stone section. The stone outlet for a sediment trap differs from that for a stone outlet structure because of the intentional ponding of water behind the stone. To provide for a ponding area, a relatively impervious core (e.g., timber, concrete block, or straw bales) is placed in the stone. The core should be covered by 6 in. of stone.

133. The crest width of the outlet should be sized to pass the design storm. The crest of the outlet (top of stone) should be at least 1 ft below the top of the embankment. The crushed stone used in the outlet should be



Excavated earth outlet sediment trap

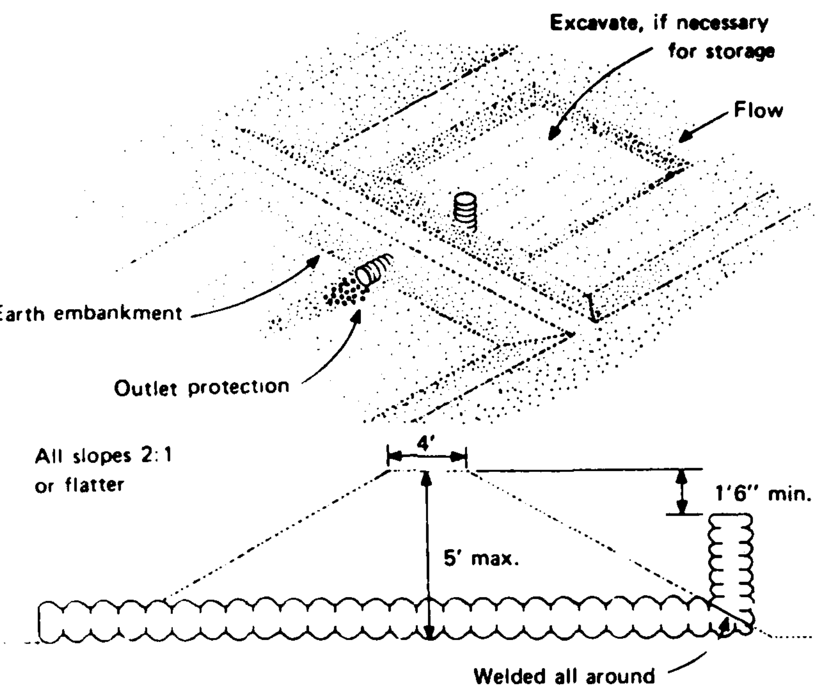
Embankment earth outlet sediment trap

Construction Specifications

1. Area under embankment should be cleared, grubbed, and stripped of any vegetation and root mat. The pool area should be cleared.
2. The fill material for the embankment should be free of roots or other woody vegetation as well as oversized stones, rocks, organic material, or other objectionable material. The embankment should be compacted by traversing with equipment while it is being constructed.
3. Sediment should be removed and trap restored to its original dimensions when the sediment has accumulated to one-half the design depth of the trap. Removed sediment should be deposited in a suitable area and in such a manner that it will not erode.
4. The structure should be inspected after each rain and repairs made as needed.
5. Construction operations should be carried out in such a manner that erosion and water pollution are minimized.
6. The structure should be removed and area stabilized when the drainage area has been properly stabilized.
7. All cut and fill slopes should be 2:1 or flatter.
8. Outlet crest evaluation should be at least 1 foot below the top of the embankment.

Note: The earthen embankment should be seeded with temporary or permanent vegetation within 15 days of construction.

Figure D-33. Earth outlet sediment trap (USEPA 1976)



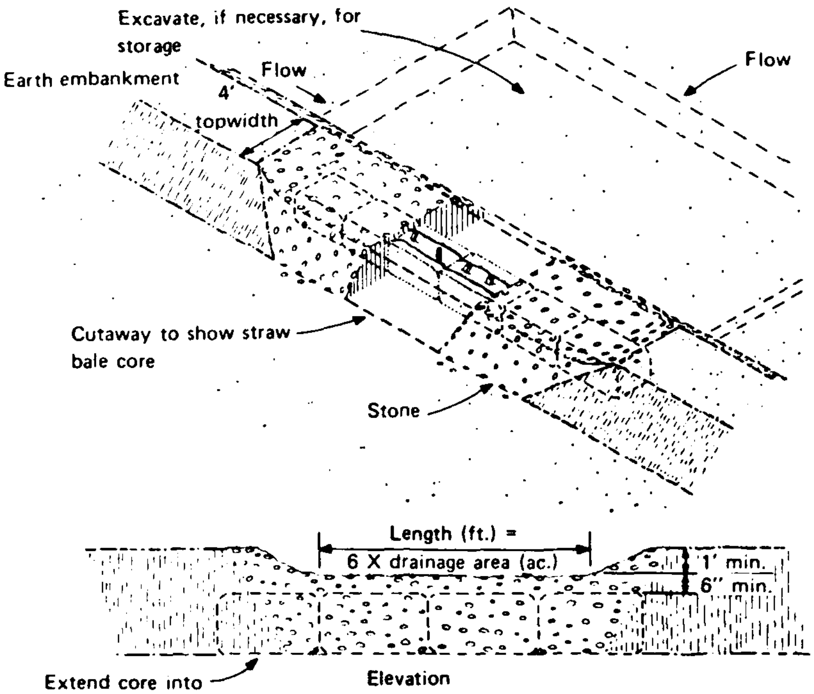
Embankment section thru riser

Construction Specifications

1. Area under embankment should be cleared, grubbed, and stripped of any vegetation and root mat. The pool area should be cleared.
2. The fill material for the embankment should be free of roots or other woody vegetation as well as oversized stones, rocks, organic material, or other objectionable material. The embankment should be compacted by traversing with equipment while it is being constructed.
3. Sediment should be removed and trap restored to its original dimensions when the sediment has accumulated to one-half the design depth of the trap. Removed sediment should be deposited in a suitable area and in such a manner that it will not erode.
4. The structure should be inspected after each rain and repairs made as needed.
5. Construction operations should be carried out in such a manner that erosion and water pollution are minimized.
6. The structure should be removed and area stabilized when the drainage area has been properly stabilized.
7. All cut and fill slopes should be 2:1 or flatter.
8. All pipe connections should be watertight.
9. Fill material around the pipe spillway should be hand compacted in 4-inch layers. A minimum of 2 feet of hand-compacted backfill should be placed over the pipe spillway before crossing it with construction equipment.

Note: The earthen embankment should be seeded with temporary or permanent vegetation within 15 days of construction.

Figure D-34. Pipe outlet sediment trap (USEPA 1976)



Construction Specifications

1. Area under embankment should be cleared, grubbed, and stripped of any vegetation and root mat. The pool area should be cleared.
2. The fill material for the embankment should be free of roots or other woody vegetation as well as oversized stones, rocks, organic material, or other objectionable material. The embankment should be compacted by traversing with equipment while it is being constructed.
3. Sediment should be removed and trap restored to its original dimensions when the sediment has accumulated to one-half the design depth of the trap. Removed sediment should be deposited in a suitable area and in such a manner that it will not erode.
4. The structure should be inspected after each rain and repairs made as needed.
5. Construction operations should be carried out in such a manner that erosion and water pollution are minimized.
6. The structure should be removed and the area stabilized when the drainage area has been properly stabilized.
7. All cut and fill slopes should be 2:1 or flatter.
8. The crushed stone used in the outlet should be AASHTO M43, Size No. 2 or 24, or equivalent. Gravel meeting the above gradation may be used if crushed stone is not available. Crusher run is not acceptable.

Note: Drawings show straw bales used for core. Bales are anchored according to construction specifications for straw bale dikes (see Figure D-36). Other materials (e.g., timber or concrete block) may also be used for core. Firmly anchor all core material to ground.

Figure D-35. Stone outlet sediment trap (USEPA 1976)

Table D-6

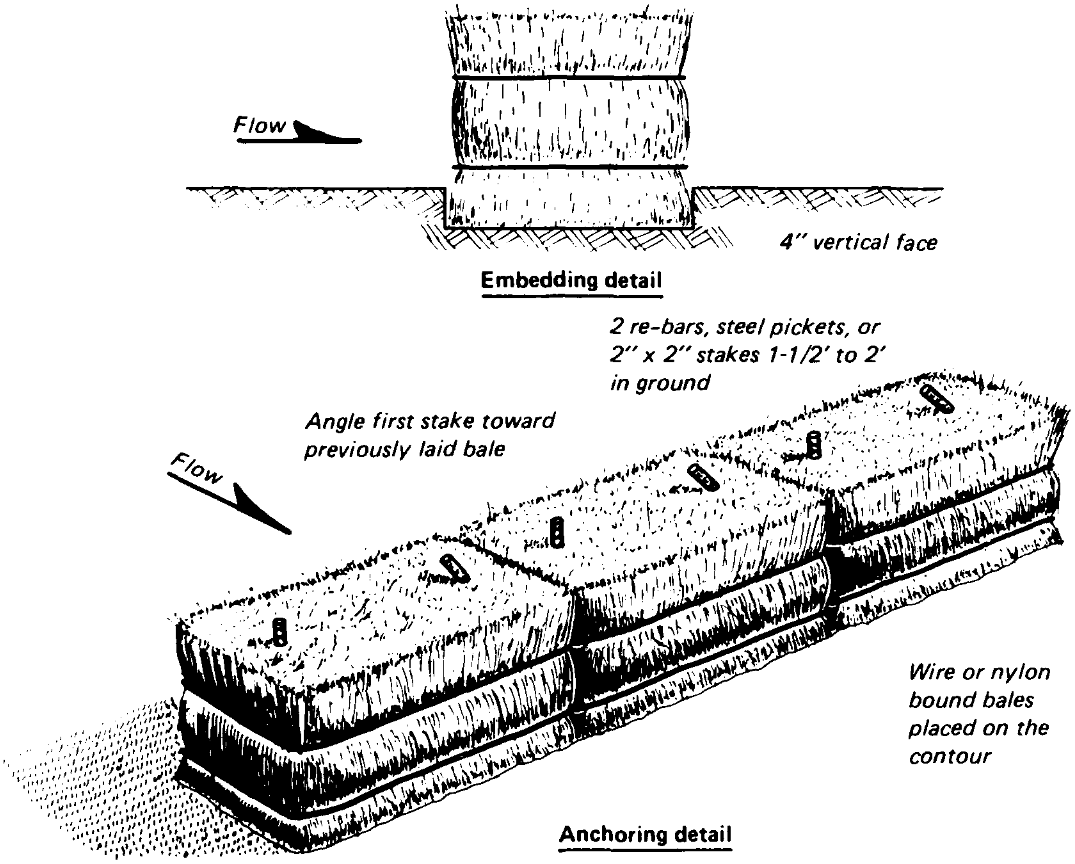
Pipe Diameter for Pipe Outlet Sediment Trap

Maximum Drainage Area, acres	Minimum Pipe Diameter, in.
1	12
2	18
3	21
4	24
5	30

AASHTO M43, size No. 2 or 24, or equivalent. Gravel meeting the above gradation may be used if crushed stone is not available. See Figure D-35 for details.

Maintenance

134. Sediment should be removed and the trap restored to its original dimensions when the sediment has accumulated to one half the design volume of the trap. Sediment removed from the basin should be deposited in a suitable area so that it will not erode. The structure should be checked regularly to ensure that it is structurally sound and has not been damaged by erosion or construction equipment. The height of the outlet should be checked to ensure that its center is at least 1 ft below the top of the embankment.



Construction Specifications

1. Bales should be placed in a row with ends tightly abutting the adjacent bales.
2. Each bale should be embedded in the soil a minimum of 4".
3. Bales should be securely anchored in place by stakes or re-bars driven through the bales. The first stake in each bale should be angled toward previously laid bale to force bales together.
4. Inspection should be frequent and repair or replacement shall be made promptly as needed.
5. Bales should be removed when they have served their usefulness so as not to block or impede storm flow or drainage.

Figure D-36. Straw bale dike (for drainage area less than 1/2 acre (USEPA 1976)

SODDING

135. Sodding (Figure D-37) is the stabilizing of fine-graded disturbed areas by establishing permanent grass stands with sod. Its main purposes are:

- a. To establish permanent turf immediately.
- b. To prevent erosion and damage from sediment and runoff by stabilizing the soil surface.
- c. To reduce the production of dust and mud associated with bare soil surfaces.
- d. To stabilize drainageways where concentrated overland flow will occur.

Figure D-37. Photo of sodding

Applicability

136. Sodding is not commonly used at Corps construction sites. However, sodding represents an alternative which can be applied to disturbed areas which require immediate vegetative cover, or where sodding is preferred to other means of grass establishment. Locations particularly suited to stabilization with sod are:

- a. Waterways carrying intermittent flow.
- b. Areas adjacent to waterways and other water bodies.
- c. Areas around drop inlets in grassed swales.

137. The use of sod is limited to humid climates because of the high moisture requirements needed to establish and maintain adequate cover.

order to improve the growth of vegetation, or to remove surface water. They are installed along a slope and drain in the direction of the slope. They can be installed in a parallel pattern, a herringbone pattern, or a random pattern (Figure D-40).

186. Interceptor drains are used to remove water as it seeps down a slope to prevent the soil from becoming saturated and subject to slippage. They are installed across a slope and drain to the side of the slope. They usually consist of a single pipe or series of single pipes instead of a patterned layout (Figure D-41).

Design Criteria

Location

187. Tree roots can often clog subsurface drain systems. Consequently, subsurface drains should be located accordingly (Construction Specifications).

188. Relief drain. Relief drains should be located through the center of wet areas. They should drain in the same direction as the slope.

189. Interceptor drains. Interceptor drains should be located on the uphill side of wet areas. They should be installed across the slope and drain to the side of the slope.

Capacity of drains

190. The required capacity of a subsurface drain depends upon its use.

191. Relief drains. Relief drains installed in a uniform pattern should remove a minimum of 1 in. of ground water in 24 hr (0.042 cfs/acre). The design capacity must be increased accordingly to accommodate any surface water which enters directly into the system (Figure D-42).

192. Interceptor drains or relief drains in a random pattern. Interceptor drains or relief drains installed in a random pattern should remove a minimum of 1.5 cfs/1000 ft of length. This value should be increased for sloping land according to the values in Table D-8. In addition, if a flowing spring or surface water enters directly into the system, this flow must be accommodated and the design capacity must be increased accordingly to take care of this flow (Figure D-42).

SUBSURFACE DRAINS

181. A subsurface drain is a perforated conduit such as pipe, tubing, or tile installed beneath the ground to intercept, collect, and/or convey ground water. A drain may serve one or more of the following purposes:

- a. Improve the soil environment for vegetative growth by regulating the water table and ground-water flow.
- b. Intercept and prevent additional ground-water movement into an already wet area.
- c. Relieve artesian pressure.
- d. Remove surface runoff.
- e. Serve as an outlet for other drains.
- f. Replace natural subsurface drainage patterns that are interrupted or destroyed by construction operations.
- g. Collect ground water for beneficial uses.

Applicability

182. Subsurface drains are used wherever excess water must be removed from the soil. This does not apply to the installation of foundation drainage systems for buildings.

183. Drains are used in areas having a high water table where benefits of lowering or controlling ground water or surface runoff justify the cost of installing such a system. They may also be used to intercept and divert "seeps," especially on cut or fill slopes, before they can surface and cause problems. The soil must have sufficient depth and permeability to permit installation of an effective and economically feasible system.

184. An outlet for the drainage system must be available, either by gravity flow or through pumping. The outlet should be adequate for the quantity and quality of effluent to be discharged with consideration of possible damage above or below the point of discharge which might involve legal actions under state or local law.

Planning Considerations

185. Subsurface drainage systems are of two types, relief drains and interceptor drains. Relief drains are used either to lower the water table in

176. Simazine and Dicamba offer good control of certain weed types when properly applied. Black plastic tarpaulins and mulches are excellent weed control measures. The tarpaulins reduce evaporation from the slope, condensing it at the soil surface, as well as concentrating runoff at the plant base.

Maintenance

Growth requirements

177. Many sprigs and plugs can be expected to root in 5 to 10 days under optimum conditions. Full coverage of the soil by spreading plants can be effected in 4 to 8 weeks with good growing conditions.

The following are essential for good growth:

a. Adequate moisture. Water immediately after planting, and water enough to keep soil moist to a depth of 4 in. during the first 4 weeks and as needed thereafter to sustain growth.

b. Sunlight. Do not permit mulches, other plantings, etc., to shade new stands.

c. Freedom from erosive forces. Keep concentrated flows of water off of new plantings for 2 weeks to 1 month.

178. Stands may be mowed when growth requires it. Certain types may be left unmowed except for once-a-year trimming to 6 in. Others may be cut at 1 to 1-1/2 in.

Fertilizer

179. The amount of fertilizer depends on the plant types. For bermudagrass, apply 33 lb per 1000 ft^2 of 12-4-8 (or equivalent) between March 1 and April 15. Fifty percent or more of the nitrogen must be water-insoluble. Other fertilization programs may be used with the approval of the local permitting authorities. Tubelings require no fertilization once planted. However, the water supply does have a significant influence on plant growth and root development.

180. To stimulate downward root growth, a heavy soaking at well-spaced intervals to allow drying from the top would be preferable to frequent light waterings. Watering cycles should be adjusted periodically as plants develop deeper root systems.

(1/4-to 1/2-lb active ingredient/acre) and 2,4-D amid form (1-lb active ingredient/acre). Use when weeds are 2 to 3 in. tall, but not before grass is well rooted.

Sources of tubelings

171. Tubelings are purchased in individual tubes, 24 in. long, and usually consist of various tree, shrub, and vine species. The county agricultural extension agent or the Soil Conservation Service district office should be contacted for information on where tubelings may be obtained.

Quantities

172. A total of 2500 to 3500 plants per acre should be used. The quantity is very dependent on the type of plant used.

When to plant (Holden and Sindelow 1971)

173. Planting of tubelings should be done during the winter when precipitation and soil moisture content are higher and greater survival rates can be expected. A thorough knowledge of soil moisture conditions is needed to determine the applicability of tubeling planting. In areas of very dry summer conditions, summer watering may be required to ensure continued survival of tubelings.

How to plant (Hawaii Department of Transportation 1976)

174. The tubeling planting method consists of drilling a hole approximately 2 ft deep and 3-1/2 in. in diameter with a one-man gasoline-powered auger. A 21-g nonburning, long-lasting fertilizer planting tablet (20-10-5) is then dropped to the bottom of the hole and the tubeling inserted. The hole is filled with water to about 12 in. and backfilled to 8 in. below the surface. A second planting tablet is then placed in the hole and the hole filled with water. After allowing the water to settle, the hole is again filled with water and backfilled to finish. A catch basin is formed about the base of the plant to trap rainfall and runoff. All plants are watered once more before leaving the area. Once planted, it is assumed that tubelings and container-grown stock will obtain water from available soil moisture and whatever precipitation occurs in the area.

Weed control

175. In order to become effectively established, tubelings must not have to compete with weeds for sunlight, water, or space.

163. Sprigs should be 3 to 5 in. long, having several nodes (joints). Plugs should have a minimum diameter of 2 in.

Quantities

164. Sprigging. Sprigging requires two to seven bushels per 1000 ft^2, or 80 to 300 bushels per acre. One bushel of sprigs is approximately equal to 1 yd^2 of sod.

165. Plugging. About 12 yd^2 of sod for 1000 ft^2, or 530 yd^2 of sod for 1 acre is required for plugging.

166. To establish quickly, sprigs should not be in a dormant state (leaves should be green). For adequate root development before cold weather begins, plantings should be made no later than midsummer. Contact local agriculture agencies for information on the optimum season for any particular type of sprig.

How to plant

167. Sprigging. Sprigs may be broadcast over the surface by hand, planted in rows by machine, or applied with a hydroseeder. Machines are available which insert sprigs properly and firm the soil over them. When sprigs are broadcast or hydrosprigged, they should be partially covered with soil by light disking or topdressing with good soil. Ideally, half of the sprigs should be covered with soil, and half (including some leaves) should be exposed. Soil should be firmed over the sprigs by using a cultipacker, or by rolling or tamping. When planted in rows, sprigs should be placed no more than 12 in. apart in rows 12 to 18 in. apart. Closer spacing is recommended for steep slopes, waterways, and highly erodible soils.

168. Plugging. Plugs should be inserted in the soil surface with the leaf tips above the surrounding soil and tamped firmly in place. Plugs should be placed in grid pattern on 12- to 18-in. centers. Closer spacing is recommended on critical areas. Plugs are usually placed by hand, but machines are available which can plug automatically.

Weed control

169. To become effectively established, sprigs should not have to compete with weeds for sunlight, water, or space. Cultivating is impractical as growing stolons may be injured.

170. Simazine, applied within 1 or 2 days after planting, gives excellent control of most broadleaf and grassy weeds. Use 1-1/2 to 2 lb active ingredient per acre. For control of broadleaf weeds only, apply Dicamba

b. Install any necessary erosion and sediment control practices prior to vegetation establishment. Carry out final grading according to the site restoration plan.

c. Surfaces should be roughened.

d. The soil should be free of debris, trash, roots, and weeds.

Lime and fertilizer

157. Soil tests should be made by a state laboratory or a reputable commercial laboratory (see Appendix C) to determine the requirements for lime and fertilizer. Information on state soil tests is available from county or city agricultural extension agents. Where soil tests cannot be obtained, the following soil amendments may be made:

a. Pulverized agricultural limestone. 100 lb/1000 ft^2 (2 tons/acre). Note: Only carbonate forms of lime may be used. Dolomitic limestone can be used in certain instances.

b. Fertilizer. 500 lb 10-20-20/acre (12 lb/1000 ft^2). Note: Equivalent nutrients may be applied with other fertilizer formulations.

158. The limestone and fertilizer should be spread evenly over the area to be sprigged, and incorporated into the top 3 to 6 in. of the soil by disking, harrowing, or other acceptable means.

159. Irregularities in the soil surface should be filled or leveled in order to prevent the formation of water pockets.

160. Sprigs or sod are perishable and should not remain unplanted more than 36 hours from the time of digging. Therefore, any soil preparation, liming, and fertilizing should be completed by this delivery date. Mildew or leaf yellowing may be an indication of turf damage.

161. Tubelings require very little fertilizer in their final site. Fertilizer used during the growing process is also limited since excessive fertilization would result in a relatively restricted root system. During planting, two 21-g nonburning, long-lasting fertilizer planting tablets (20-10-5) are used per plant.

Sources of sprigs and plugs

162. Sprigs can be purchased as sod and then shredded or can often be purchased by the bushel. For turf-type vegetation, Certified or Approved sod sources should be used. Contact the county or city agricultural extension agent or the Soil Conservation Service district office for information on where these materials may be obtained. Plugs may be cut from sod as needed or purchased precut.

Stonlons (runners) are aboveground stems that spread by creeping on the soil surface.

151. Bermudagrass sprigs are particularly suited for use in grasslined waterways. Depending upon the soil type, an established stand of bermudagrass can tolerate intermittent concentrated flows of water on slopes up to 10 percent. It is important to divert runoff from the waterway during the first 3 weeks of establishment to permit bermudagrass to take root. Should diversion be impractical, sod should be used to prevent washout.

152. Irrigation systems must be available during the establishment phase of sprigging.

Plugging

153. Plugs are small sections of sod which are pressed into precut holes in the soil so that topgrowth is flush to the surface and leaves are exposed. Plugs are usually planted by hand.

Tubelings

154. Tubelings are used primarily in regions of low annual or highly seasonal rainfall where the probability of successful revegetation of these areas by conventional planting methods and without installation of costly permanent irrigation systems is low.

155. Tubelings are grown in long, slender paper tubes reinforced by plastic mesh sleeves. These plants are grown in a nursery until their root systems extend to the bottom of the tubes. The tubeling is then planted in deep holes usually dug by an auger. Generally, the moisture content of soils increases with depth and the long tubeling root system enables the plant to draw moisture from lower soil levels, thus increasing its ability to survive without extensive irrigation.

Specifications

Soil preparation

156. Procedures for preparing the soil are the same for sprigging, plugging, and tubelings:

a. Most plants used for sprigging require well-drained soil loose enough for root penetration, having a pH range between 6.0 and 8.0, and free of toxic amounts of materials harmful to plant growth. Tubelings are useful where little soil moisture is available.

SPRIGGING, PLUGGING, AND TUBELING

147. Sprigging and tubeling essentially involve the planting of sprigs, stolons, or plugs to establish a vegetative cover. Tubelings differ from sprigs in that they are plants which are grown in long, slender paper tubes reinforced by plastic mesh sleeves. Plugging involves the placement of small sod plugs into precut holes. The main purposes of sprigging and tubeling are:

- a. To reduce erosion and decrease sediment yield from disturbed areas.
- b. To stabilize disturbed areas with a specific plant material suited to the site which cannot be established by seed.
- c. To establish vegetative cover more rapidly than would be possible using seed.

Applicability

148. The following are conditions under which sprigging, plugging, and tubeling techniques are used:

- a. They are very useful in areas where establishment with sod is not preferred.
- b. Sprigging can be used where intermittent concentrated flows are expected. It is especially useful for use in grassland waterways.
- c. Tubelings are very useful when used in regions of low annual or highly seasonal rainfall and where irrigation systems are not available.

Planning Considerations

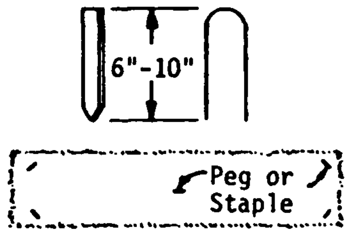
149. Turf may be established most rapidly and efficiently with sod. Where speed is essential and cost is not an overriding constraint, sod should be used (see Sodding). However, where sod cannot be used, sprigging or tubeling may be preferred.

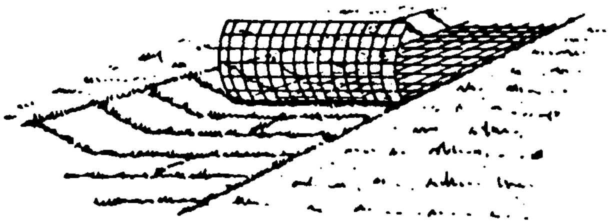
Sprigging

150. Sprigging usually consists of a mixture of sprigs and stolons. A sprig is a small section of rhizome (underground stem) 3 to 5 in. long, with at least one node or joint. All nodal points should have leaves present.

Lay sod across the direction of flow.

Use pegs or staples to fasten sod firmly - at the ends of strips and in the center, or every 3-4 feet if the strips are long. When ready to mow, drive pegs or staples flush with the ground.



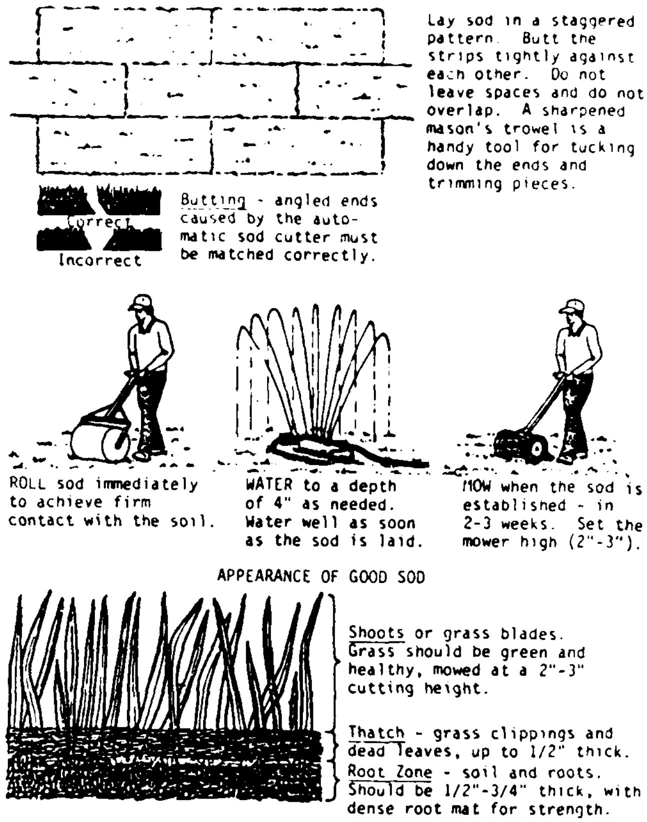


In critical areas, secure sod with chicken wire or netting. Use staples.

Construction Specifications

1. The soil should be prepared carefully and the sod should be able to withstand the designed velocity (see Waterways).
2. Lay sod strips in waterways perpendicular to the direction of flow. Ends of strips should be butted tightly.
3. After rolling or tamping, sod should be pegged or stapled to resist washout during establishment period. In critical areas, chicken wire, jute, or other netting may be pegged over the sod for extra protection.
4. After the first week, sod should be watered as necessary to maintain adequate moisture in the root zone and prevent dormancy of sod.
5. The grass height should be maintained between two and three inches unless otherwise specified. A maximum of 1/3 of the shoot (grass leaf) should be removed in any mowing.
6. Fertilization and lime will probably be required after the first growing season. Soil test recommendations and local agency guidelines will help in establishing maintenance procedures and fertilization rates.

Figure D-39. Sodded waterways (VSWCC 1980)



Construction Specifications

1. Sod should not be laid on frozen soil surfaces.

2. Lightly irrigate the soil immediately before laying the sod in hot weather since high temperatures may cause root burning and dieback.

3. Lay sod in a straight line with rows parallel to and butting tightly against each other. Stagger lateral joints to promote more uniform growth and strength. Sod should not be stretched or overlapped. Butt all joints tightly in order to prevent voids which would cause drying of the roots.

4. On slopes 3:1 or greater, or wherever erosion may be a problem, sod should be laid with staggered joints and secured by pegging or other approved methods. Install sod with the length perpendicular to the slope (on the contour).

5. As sodding of clearly defined areas is completed, roll and tamp sod to provide firm contact between roots and soil.

6. After rolling, irrigate sod to thoroughly wet the underside of the sod pad and the soil four inches below the sod.

7. During the first week, in the absence of adequate rainfall, watering should be performed as often as necessary to maintain moist soil to a depth of at least four inches.

8. Once the sod is firmly rooted (2 to 3 weeks), it can be mowed. Remove no more than 1/3 of the grass leaf at any one cutting.

Figure D-38. Sod installation (VSWCC 1980)

Table D-7

Types of Sod Available in the Eastern United States and Recommended Uses (Adapted From VSWCC 1980)

Types

Kentucky Bluegrass	Varieties: Adelphi, Merion, Kenblue, South Dakota Certified, Baron, Birka, Fylking, Plush, Sydsport, Victa. Note: A blend of varieties should always be used in Kentucky Bluegrass sod. May contain up to 20 percent Pennlawn creeping red fescue.
Tall Fescue	Varieties: Kentucky 31. Note: May contain up to 10 percent Kenblue or South Dakota Certified Kentucky Bluegrass.
Bermudagrass	Varieties: Midiron, Tufcote, Tifgreen, Tifway.

Uses

Kentucky Bluegrass	Adapted to the Northern Piedmont and Mountain Regions. Also used in West Virginia, Pennsylvania, Ohio, Kentucky, Illinois, and Indiana.
Tall Fescue	Adapted throughout Virginia, Kentucky, Tennessee, Alabama, east Texas, southern Illinois, southern Indiana, southern Ohio, parts of Missouri, southern Piedmont and the Atlantic and Gulf Coastal Plain.
Bermudagrass	Bermudagrass is used in southern Virginia, southern Kentucky, Tennessee, Alabama, east Texas, southern Piedmont and the Atlantic and Gulf Coastal Plain. Note: Common bermudagrass should not be used, as it often winterkills, is aggressive, and can become a nuisance.

c. Sod is machine cut at a uniform soil thickness of 3/4 in., plus or minus 1/4 in., excluding shoot growth and thatch.

d. Pieces of sod are cut to the supplier's standard width and length, with a maximum allowable deviation in any dimension of 5 percent.

e. Standard-size sections of sod should be strong enough to support their own weight and retain their size and shape when suspended from a firm grasp on one end of the section.

f. Sod should not be cut or laid in excessively wet or dry weather.

g. Sod should be harvested, delivered, and installed within a period of 36 hr.

Choosing appropriate types of sod

145. The type of sod used must be composed of plants adapted to the locality. Table D-7 lists the types of sod available for use in the Eastern United States. Consult local agencies for types of sod best suited to other area. Figure D-38 depicts sod installation.

146. Specifications for sodded waterways are shown in Figure D-39.

b. Soil tests should be made to determine the requirements for lime and fertilizer. Soil tests may be conducted by state laboratories or a reputable commercial laboratory (Appendix C). Additional information on state soil tests is available from county or city agricultural extension agents. Under difficult circumstances where it is not possible to obtain a soil test, the following soil amendments can be made:

(1) Pulverized agricultural limestone at 100 lb/1000 ft^2 (2 tons/acre). NOTE: Only carbonate forms of lime may be used. Dolomitic limestone should be used on Coastal Plains. Alkaline soils do not require lime.

(2) Fertilizer at 25 lb/1000 ft^2 (1000 lb/acre) of 10-10- 10 in fall, or 25 lb/1000 ft^2 of 5-10-10 in spring. NOTE: Equivalent nutrients may be applied with other fertilizer formulations.

(3) Spread the limestone and fertilizer evenly over the area to be sodded, and incorporate it into the top 3 to 6 in. of soil by disking, harrowing, or other acceptable means.

(4) These recommendations should be discussed and updated with local state and county agriculture extension agents before implementation.

c. Prior to laying sod, the soil surface should be free of trash, debris, roots, branches, stones, and clods in excess of 2 in. in length or diameter. Sod should not be applied to gravel or other nonsoil surfaces.

d. Fill in or level any irregularities in the soil surface to prevent the formation of depressions or water pockets.

e. Do not spread sod on soil which has been treated with soil sterilants or herbicides until enough time has elasped to permit dissipation of toxic materials.

Quality of sod

144. Quality of sod specifications include:

a. Sod used for most surface mining operations need not be state certified or state approved. However, certified turfgrass sod grown from certified seed, and inspected and certified by the state in which it will be used, ensures genetic purity, high quality, freedom from noxious weeds, and freedom from excessive insect or disease problems. This sod meets published state standards and bears the official state "Certified Turf" label on the bill of lading.

b. Approved turfgrass is inspected and approved by the certifying agency of the state in which it will be used. It does not meet the quality standards of Certified Turf, but does contain the same varieties recommended in the Certified program. The sod must meet published state standards and bear an official state "Approved Turf" label on the bill of lading.

Planning Considerations

138. The successful establishment of quality turfgrass is difficult in many parts of the country due to extremes in temperature and moisture. The selection of appropriate turf-establishment methods requires a great deal of planning as a quality turf can be established with either seed or sod. Soil preparation is the same for the two methods. The advantages of properly installed sod include:

- a. Immediate erosion control.
- b. An instant green surface with no dust or mud.
- c. Nearly year-round establishment capability.
- d. Less chance of failure than wit' seed.
- e. Freedom from weeds.
- f. Quick use of the sodded surface.
- g. The option of buying a quality-controlled product with predictable results.

139. It is initially more costly to install sod than to seed. However, this cost is justified in places where sod can perform better than seed in controlling erosion.

140. Properly pegged sod in swales and waterways provides immediate channel protection, while drop inlets can be kept free of mulch, seed, and mud, while maintaining the grade, by framing the inlet with sod strips.

141. Sod can be laid during times of the year when seeded grass may fail, so long as there is adequate water available for irrigation in the early weeks.

142. Ground preparation and proper maintenance are also important with sod as with seed. Sod is composed of living plants and those plants must receive adequate care in order to provide vegetative stabilization on a disturbed area.

Specifications

Soil preparation

143. Soil preparation specifications are given below:

- a. Prior to soil preparation, bring areas ιo be sodded to final grade in accordance with the approved plan.

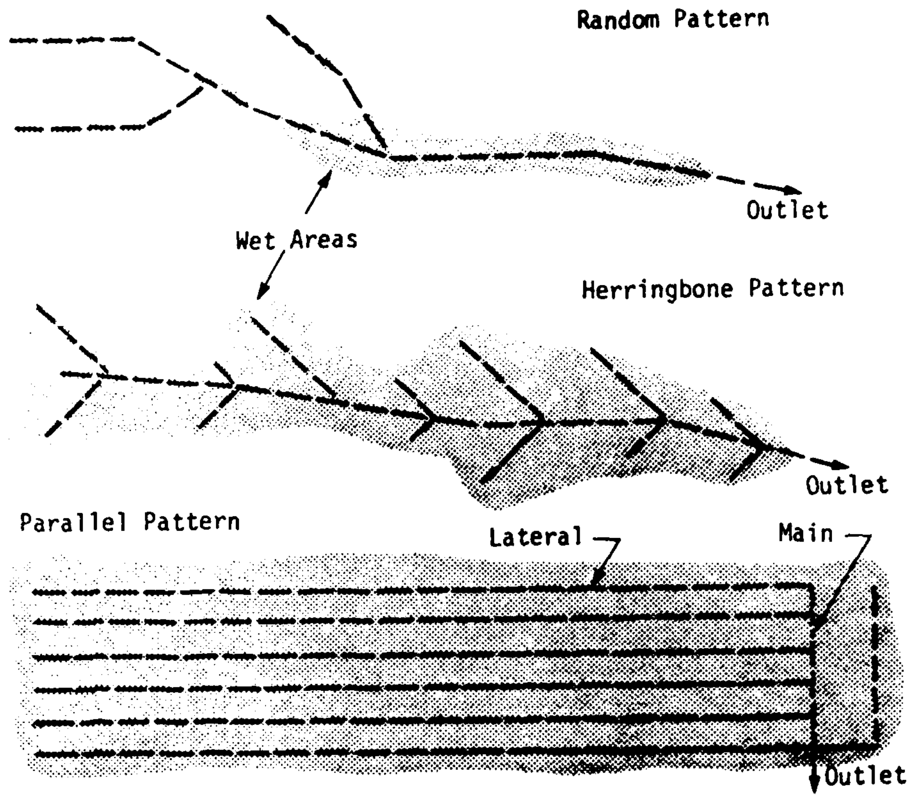


Figure D-40. Subsurface drain layouts (USDA, SCS 1971)

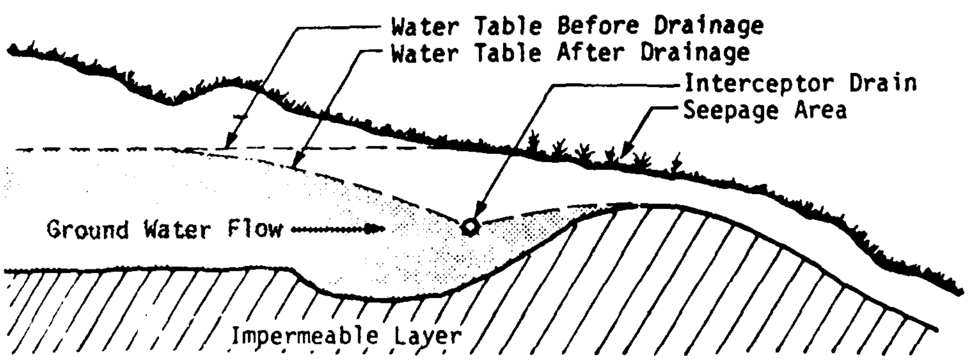


Figure D-41. Effect of subsurface drainage on the water table (USDA, SCS 1971)

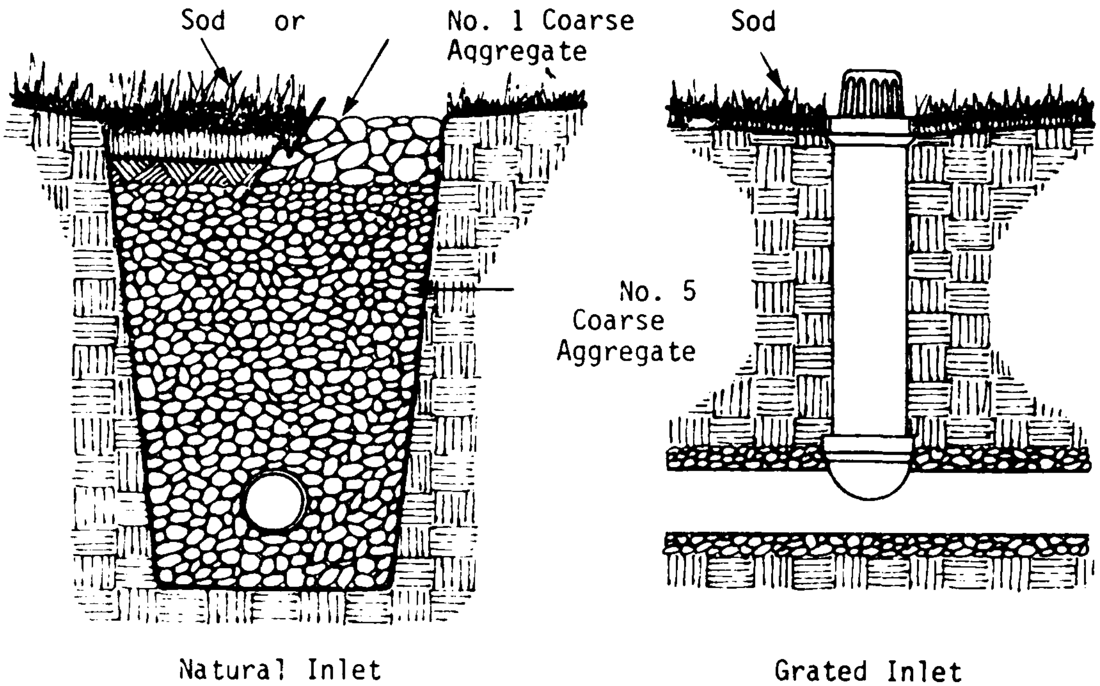


Figure D-42. Surface inlets (USDA, SCS 1971)

Table D-8

Water Removal Rates for Sloping Land

Land Slope	Water Removal Rate
2-5%	1.65 cfs/1000 ft
6-12%	1.80 cfs/1000 ft
>12%	1.95 cfs/1000 ft

Size of drains

193. Subsurface drains should be sized for the required capacity using procedures outlined under Design Procedures. The minimum diameter for a subsurface drain should be 4 in.

Depth and spacing

194. Relief drains. Relief drains installed in a uniform pattern should have equal spacing between drains and the drains should be at the same depth. Maximum depth is limited by the allowable load on the pipe, depth to impermeable layers in the soil, and outlet requirements. The minimum depth is 24 in. under normal conditions. Twelve inches is acceptable where the drain

will not be subject to equipment loading or frost action. Spacing between drains is dependent on soil permeability and the depth of the drain. In general, however, a depth of 3 ft and a spacing of 50 ft will be adequate. A more economical system may be designed, if the necessary information is available, by using the equations found under Design Procedures.

195. Interceptor drains. The depth of installation of an interceptor drain is influenced mainly by the depth to which the water table is to be lowered. The maximum depth is limited by the allowable load on the pipe and the depth to an impermeable layer. Minimum depth should be the same as for relief drains.

196. One interceptor drain is usually sufficient. However, if multiple drains are to be used, determining the required spacing can be difficult. The best approach is to install the first drain--then if seepage or high water table problems occur downslope, install an additional drain a suitable distance downslope. This distance can be calculated from equations found under Design Procedures.

Velocity and grade

197. The minimum velocity required to prevent silting is 1.4 ft/sec. The line should be graded to achieve at least this velocity. Steep grades should be avoided, however. Table D-9 lists maximum velocities for various soil textures.

Table D-9

Maximum Velocities for Various Soil Textures

Soil Texture	Maximum Velocity, ft/sec
Sandy and sandy loam	3.5
Silt and silt loam	5.0
Silty clay loam	6.0
Clay and clay loam	7.0
Coarse sand or gravel	9.0

Envelopes and filters

198. Envelopes or filters should be used around all drains for proper bedding and improved flow of ground water into the drain. The envelope should consist of 3 in. of No. 68 aggregate placed completely around the drain (Figure D-43). Aggregate gradations are found in Table D-10.

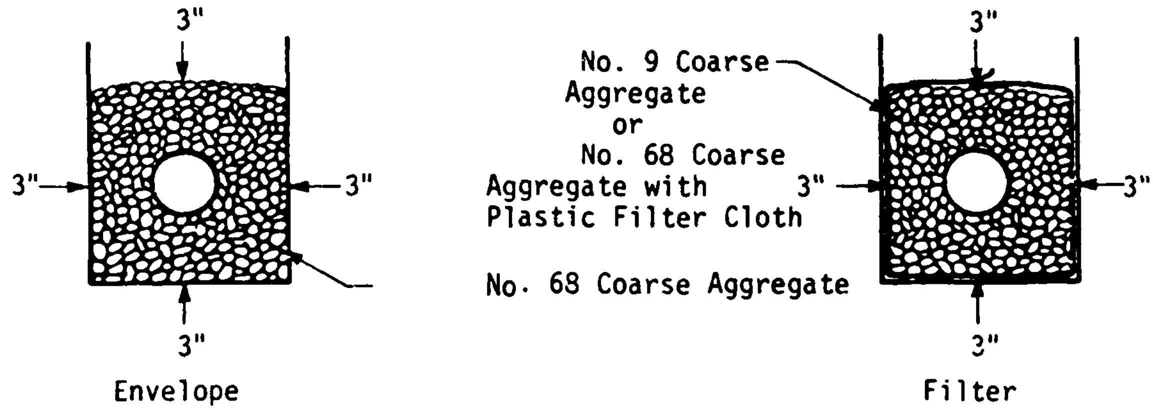


Figure D-43. Drainage envelopes and filters (USDA, SCS 1971)

Table D-10

Coarse Aggregate Gradations*

Grade	Percent	Sieve Size
No. 1	100	4 in.
	95 % 5	3-1/2 in.
	43 % 17	2-1/2 in.
	15 (Maximum)	1-1/2 in.
	5 (Maximum)	3/4 in.
No. 5	100	1-1/2 in.
	95 % 5	1 in.
	58 % 17	3/4 in.
	15 (Maximum)	1/2 in.
	5 (Maximum)	3/8 in.
No. 9	100	3/8 in.
	92 % 8	#4
	25 % 15	#8
	10 (Maximum)	#16
	5 (Maximum)	#50
No. 68	100	1 in.
	95 % 5	3/8 in.
	48 % 17	3/8 in.
	20 (Maximum)	#4
	8 (Maximum)	#8
	5 (Maximum)	#16

* Virginia Department of Highways and Transportation Specifications. Open graded, percent by weight.

199. Where high concentrations of silt and fine sand are encountered, a filter should be used instead of an envelope. The filter should consist of 3 in. of No. 9 aggregate placed completely around the drain.

200. Plastic filter cloths can be used instead of granular filters. Filter cloths should be used with a gravel envelope as shown in Figure D-43.

Surface water

201. Figure D-42 shows two types of surface water inlets. The grated inlet should not be used where sediment might be a problem.

Outlet

202. The outlet of the subsurface drain should empty into a channel or some other watercourse which will remove the water from the outlet. It should be above the mean water level in the receiving channel. It should be protected from erosion, undermining, damage from periods of submergence, and the entry of small animals into the drain.

203. The outlet should consist of a 10-ft section of corrugated metal, cast iron, or steel pipe without perforations. No envelope material should be used around the pipe. At least two-thirds of the outlet pipe length should be buried.

Placement and bedding

204. All subsurface drains, whether flexible conduit such as plastic or bituminized fiber or rigid conduit such as clay or concrete, should be laid to a neat line and grade. The conduit should be placed and bedded by one of the following methods (Figure D-44):

Type of Conduit	Special Conditions	Method
Flexible	Filter not required	1 or 4
Flexible	Filter required	
	Prefabricated	1
	Sand and gravel filter	2
Rigid	Filter not required	1 or 3
Rigid	Filter required	
	Prefabricated filter	1 or 3
	Sand and gravel filter	4
Flexible or rigid	Envelope required	4

205. Methods 1 and 1A. Where it is not necessary to encase the conduit in a sand and gravel envelope or filter, the bottom of the excavated trench is shaped to conform approximately to the shape of the conduit and the conduit is

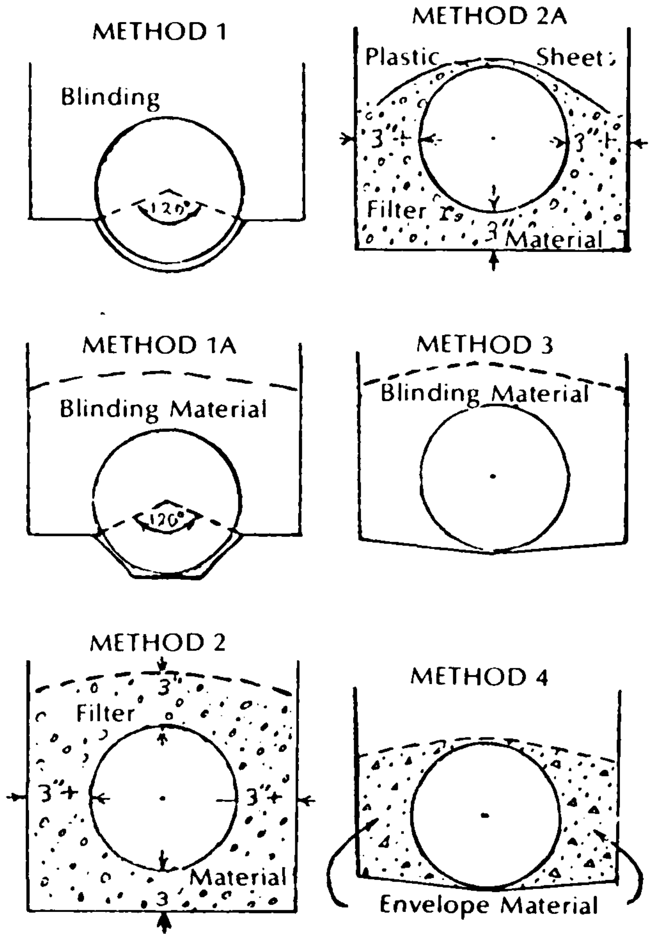


Figure D-44. Methods for placing subsurface drains (Georgia State Soil and Water Conservation Committee, no date)

laid in this groove. The groove may be semicircular or trapezoidal shaped and of such dimensions that the bottom 120 deg of the conduit is supported by undisturbed soil. Blinding and backfilling operations can be in the conventional manner using soil from the sides of the trench and excavated material.

206. Methods 2 or 2A. Where the conduit is encased in a sand and gravel filter, a minimum 3-in. depth of filter material is placed on the bottom of a conventional trench. The conduit is placed on this and the trench completely filled with filter material to a minimum depth of 3 in. above conduit. An acceptable optional method of placing the filter material is to fill the trench as indicated in 2A and cover this with an acceptable plastic (not less than 6 mil) sheet at least 6 in. wider than the conduit diameter, to separate the filter material from the backfill material.

207. Method 3. Where rigid conduit is to used, it can be placed in a conventional trench and blinded and backfilled in the conventional manner using soil from the sides of the trench and excavated material.

208. Method 4. Where it is feasible and desirable to encase the conduit in a sand and gravel envelope, the conduit is laid on the bottom of a conventional trench (no special shaping or grooving) and the trench is filled with envelope material to a level flush with the top of the conduit. The trench should be completely filled so that there are no void spaces in the area between the sides of the pipe and the walls of the trench. Backfilling can be in the conventional manner. With this method it is desirable to excavate a narrow trench to conserve on envelope material. The minimum envelope depth should be equal to the outside diameter of the conduit.

Materials

209. Drains include conduits of clay, concrete, bituminized fiber, metal, plastic, or other materials of acceptable quality. The conduit should meet strength and durability requirements of the site. Current specifications as listed below should be used in determining the quality of the conduit. The following specifications cover the products currently acceptable for use as drains or for use in determining quality of materials used in drainage installations:

Drain product	Specification
Clay drain tile	ASTM C 4
Clay drain tile, perforated	ASTM C 498
Clay pipe, perforated, standard, and extra strength	ASTM C 700
Clay pipe, testing	ASTM C 301
Concrete drain tile	ASTM C 412
Concrete pipe for irrigation or drainage	ASTM C 118
Concrete pipe or tile, determining physical properties of	ASTM C 497
Concrete sewer, storm drain, and culvert pipe	ASTM C 14
Reinforced concrete culvert, storm drain, and sewer pipe	ASTM C 76
Perforated concrete pipe	ASTM C 444

Drain product	Specification
Portland cement	ASTM C 150
Asbestos-cement nonpressure sewer pipe	ASTM C 428
Asbestos-cement perforated underdrain pipe	ASTM C 508
Asbestos-cement pipe, testing	ASTM C 500
Pipe, bituminized fiber (and fittings)	Fed. Spec. SS-P-1540
Homogeneous perforated bituminized fiber pipe for general drainage	ASTM D 2311
Homogeneous perforated fiber pipe, testing	ASTM D 2314
Laminated-wall bituminized fiber perforated pipe for agricultural, land, and general drainage	ASTM D 2417
Laminated-wall bituminized fiber pipe, physical testing of	ASTM D 2315
Styrene rubber plastic drain and building sewer pipe and fittings (perforations, if needed, are specified in ASTM D 2311)	ASTM D 2852
Plastic drainage tubing, corrugated	Soil Conservation Service Specifications
Pipe, corrugated (aluminum alloy)	Fed. Spec. WW-P-402
Pipe, corrugated (iron or steel, zinc coated)	Fed. Spec. WW-P-405

210. Round perforations up to 5/8 in. in diameter with hole spacings to 5 in. on center may be used if special blinding, envelope, or filter requirements are used. The special requirements specified must be compatible with the perforation and soil situation to ensure satisfactory drain performance.

211. Clay tile. These specifications may be modified as follows: where clay tile will not be subject to freezing and thawing hazards, before or during installation, and where the average frost depth is less than 18 in., the freezing and thawing and absorption tests may be modified or waived.

212. Concrete tile. The use of concrete tile under acid and sulfate conditions should be in accord with the guides in Table D-11.

213. Other clay and concrete pipe. Bell and spigot, tongue and groove, and other pipe which meets the strength, absorption, and other requirements of clay or concrete tile as covered above, except for minor imperfections in the

Table D-11

Conditions for Use of Concrete Tiles (Georgia State Soil and Water Conservation Committee, no date)

Acid Soils

Class of Tile	Lower Permissible Limits of pH Values* Organic and Sandy Soils	Medium and Heavy-Textured Soils
ASTM C 412:		
Standard quality	6.5	6.0
Extra quality	6.0	5.5
Heavy-duty extra-quality	6.0	5.5
Special quality	5.5	5.0
ASTM C 14, C 118, C 444	5.5	5.0

Sulfate Soils

Permissible Maximum Limit of Sulfates Singly or in Combination**	Type of Tile and Cement (Minimum)	
(Parts per Million)		
7000	Tile:	ASTM C 412 Special quality C 14, C 118, C 444
	Cement:	ASTM C 150 Type V
3000	Tile:	ASTM C 412 Extra quality and heavy-duty extra-quality C 14, C 118, C 444
	Cement:	ASTM C 150 Type II or V
1000	Tile:	ASTM C 412 Standard quality C 14, C 118, C 444
	Cement:	ASTM C 150 - Any type

* Figures given represent the lowest readings of pH values for ground water or soil at tile depth.

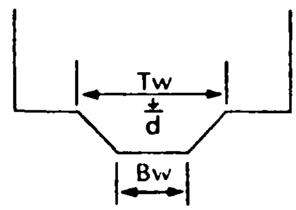
** Highest reading of sulfates for soil or ground water at tile depth.

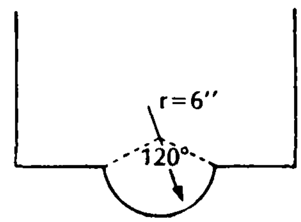
bell, the spigot tongue or the groove, and ordinarily classed by the industry as "seconds," may be used for drainage conduits provided the pipe is otherwise adequate for the job (Table D-12).

Table D-12

Allowable Trapezoidal* Grooves for Bedding Corrugated Polyethylene Drainage Tubing

Nominal Tube Diameter (d) (Inches)	Groove (d) depth (Inches)	Groove (Tw) top width (Inches)	Groove (Bw) bottom width (Inches)
4	1.1	4.1	1.8
5	1.4	5.1	2.3
6	1.7	6.2	2.9
8	2.1	8.0	3.7
4 & 5	1.5	5.1	2.1
4, 5, & 6	2.0	6.2	2.3
4, 5, 6, & 8	2.8	8.0	2.4**
6 & 8	2.4	8.0	3.3
5, 6, & 8	2.5	8.0	3.0





r=radius of curvature

(Georgia State Soil and Water Conservation Commission, no date)

* These trapezoidal grooves with 45-deg side slopes will provide support similar to that provided with a circular groove shaped to fit the lower 120 deg of circumference.

** The groove dimensions shown on this line are for use with the semi-trapezoidal groove shown. Bottom radius of curvature must be 6 in. or less.

Construction Specifications

Inspection and handling of materials

214. Material for subsurface drains should be given careful inspection before installation. Only materials of acceptable strength and quality should be placed in the trench. Damaged and inferior materials should be rejected.

Rejected tiles should be broken so that they will not be used in drains elsewhere.

215. Clay and concrete drain tile should not be stockpiled in contact with the ground, permitting alternate freezing and thawing, prior to installation. Bituminized fiber and plastic pipe and tubing should be protected from hazards causing deformation or warping.

216. All water-loving trees such as willow, elm, soft maple, and cottonwood should be removed for a distance of 100 ft on each side of the tile line. A clearance of 50 ft should be maintained from other species of trees, shrubs, or vines. If the trees cannot be removed or the line rerouted, a closed tile line with sealed joints should be constructed. This type of construction should extend throughout the root zone of the tree or trees. Rapid plugging with roots can be expected when drains are not isolated or protected as described above.

Foundation requirements

217. Soft or yielding foundations should be stabilized where required and lines protected from settlement by adding gravel or other suitable material to the trench, by placing the conduit on plank or other rigid support, or by using long sections of perforated or watertight pipe with adequate strength to ensure satisfactory subsurface drain performance.

Placement (Iowa Department of Soil Conservation, no date)

218. General. All subsurface drains should be laid to line and grade and covered with approved blinding, envelope, or filter material to a depth of not less than 3 in. over the top of the drain. If the option to install an impervious sheet over the drain is used, at least 3 in. of blinding material must cover the sheet.

219. Where the conduit is to be laid in a rock trench, or where rock is exposed at the bottom of the trench, the rock should be removed below grade enough that the trench may be backfilled, compacted, and bedded. When completed, the conduit should be not less than 2 in. from rock.

220. Earth backfill material should be placed in the trench in such a manner that displacement of the conduit will not occur and so that the filter and bedding material, after backfilling, will meet the requirements of the plans and specifications.

221. When a filter is required, all openings in the subsurface drain should be protected by the filter, or the bottom and sides of the conduit are to be protected by the filter and top of the conduit as well as part of side filter material is to be covered by a sheet of impervious plastic. No portion of the conduit containing openings is to be left exposed under conditions which require the use of a filter.

222. When sand-gravel filtered material is used, the trench should be overexcavated 3 in. and backfilled to grade with filter material. After placement of the conduit upon the filter material, additional filter material should be placed over the conduit to fill the trench to a depth of 3 in. over the conduit. A plastic sheet and friable soil can be used in lieu of filter material as the backfill over the subsurface drain when specified. The sand-gravel filter material should be a mixture of sand and gravel within the gradation required by the base material in the trench.

223. Rigid conduit (clay drain tile, concrete drain tile, etc.). The following requirements for rigid conduit should be considered:

a. Connections, depth limitations, blinding, backfilling, and protection of the line during installation should be in accordance with local specifications.

b. Joints

(1) Crack width for lateral tile should vary with the type of soil:

(a) Peat and muck - 1/4 in. preferred; 3/8 in. maximum.

(b) Clay soils - 1/8 in. preferred; 1/4 in. maximum.

(c) Silt and loam soils - 1/16 in. preferred; 1/8 in. maximum.

(d) Sandy soils - tightest fit possible.

(2) When the tiles are laid in fine sand, they should be turned as necessary to leave the least possible crack opening and a filter should be provided to prevent the fine material from entering the tile.

(3) Crack opening for mains which serve only to collect and transport drainage water from lateral tile lines should be the tightest fit possible.

c. Alignment. A change in horizontal direction may be made by using one of the following methods:

(1) A gradual curve of the tile trench on a radius that the trenching machine can dig and still maintain grade. Tile must be shaped or chipped so that no crack between tiles exceeds 1/8 in. unless the crack is adequately covered to exclude soil movement to the tile.

(2) A manufactured or handmade bend or fitting for small diameter tile.

(3) A junction box or manhole for large diameter tile.

224. Flexible conduits (corrugated plastic drainage tubing, etc.). In addition to the above requirements, when corrugated polyethylene tubing is being installed, no more than 5 percent stretch should be allowed. Special precautions must be taken on hot bright days to be sure the stretch limit is not exceeded and excessive deflection is not caused by premature backfilling.

Grade

225. On land slopes up to 0.1 percent, deviation from the planned grade will not be greater than the fall per 100 ft of the line. On steeper grades, the tolerance will not be more than 0.1 to 0.3 ft per 100 ft depending on the grade. No reversals in the grade of the conduit will be permitted.

Backfilling

226. Earth backfill material should be placed in the trench in such a manner that displacement of the drain will not occur and so that the filter material, after backfilling, will meet the requirements shown in the plan.

227. Where the conduit is to be laid in rock trench, or where rock is exposed at the bottom of the trench, the rock should be removed below grade enough that the trench may be backfilled, compacted, and bedded; and when completed, the conduit should be no less than 2 in. from rock.

228. The outlet will be protected from surface flow over and along the line by mounding earth over the line and immediately behind the outlet to an elevation of not less than 1 ft above natural ground. All outlets will be protected with an animal guard as shown in Figure D-45.

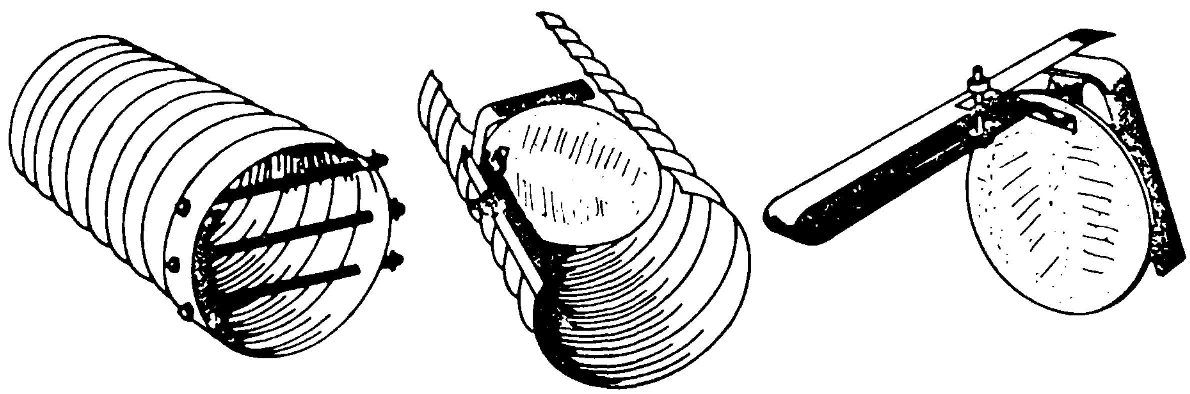


Figure D-45. Small animal guards (Georgia State Soil and Water Conservation Committee, no date)

Final cleanup

229. All trenches excavated for drain lines should be completely backfilled with excavated soil in such a manner that the ground is left reasonably smooth and suitable for establishing vegetation over the installed drain lines.

Maintenance

230. The following maintenance for subsurface drains should be considered:

a. Subsurface drains should be checked periodically to ensure that they are free-flowing and not clogged with sediment.

b. The outlet should be kept clean and free of debris.

c. Surface inlets should be kept open and free of sediment and other debris.

d. Trees located too close to a subsurface drain often clog the system with their roots. If a drain becomes clogged, relocate the drain or remove the trees.

e. Where drains are crossed by heavy vehicles, the line should be checked to ensure that it is not crushed.

Design Procedures

Subsurface drain sizes

231. Subsurface drains are not generally designed to flow under pressure and the hydraulic gradient is parallel with the grade line. Consequently, the flow is considered to be open channel and Manning's Equation can be used. The required drain size can be determined by the following procedure:

a. Determine the flow the drain must carry.

b. Determine the gradient of the drain.

c. Determine n for the type of drain pipe to be used from Table D-13. Choose the correct figures (D-46 to D-48) for the n just determined.

d. Enter the appropriate figure with the gradient of the pipe and the flow in the pipe. The insection of the two lines must be to the right of the line for 1.4 ft/sec. If it is not, increase the gradient or flow capacity or both.

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EXPERIMENT STATION VICKSBURG MS ENVIR.. C R LEE ET AL.
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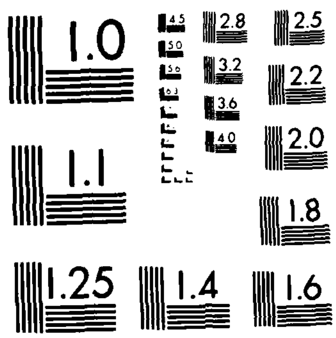

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Table D-13

"n" Values for Subsurface Drain Pipes

Composition of Pipe or Tubing	"n" Values
Asbestos cement	0.013
Bituminized fiber	0.013
Concrete	0.015
Corrugated plastic	0.015
Corrugated metal	0.025

Example 1

Given:

A random subsurface drain is to be installed on a 1.0 percent grade, 700 ft in length, and using corrugated plastic pipe.

Calculate:

The required size of the drain pipe.

Solution:

From the specifications, the required capacity of the pipe is 1.5 ft^3/sec/ 1000 ft

$$\text{Capacity} = \frac{700}{1000} \times 1.5 \text{ ft}^3/\text{sec} = 1.05 \text{ ft}^3/\text{sec}$$

From Table D-13, $n = 0.015$ for corrugated plastic pipe.

From Figure D-47, choose an 8-in. pipe.

Example 2

Given:

A relief drain installed in a parallel pattern, of eight laterals, 500 ft long, 0.5 percent grade, and 50 ft on centers. A main 400 ft in length on a 0.5 percent grade will connect to the laterals. Use bituminized fiber pipe for the main and laterals.

Calculate:

The required size of the drain pipe.

Solution:

The drainage area for each lateral is 25 ft on either side of the pipe times the length, therefore,

$$\frac{50 \text{ ft} \times 500 \text{ ft}}{43{,}560 \text{ ft}^2/\text{acre}} = 0.57 \text{ acre}$$

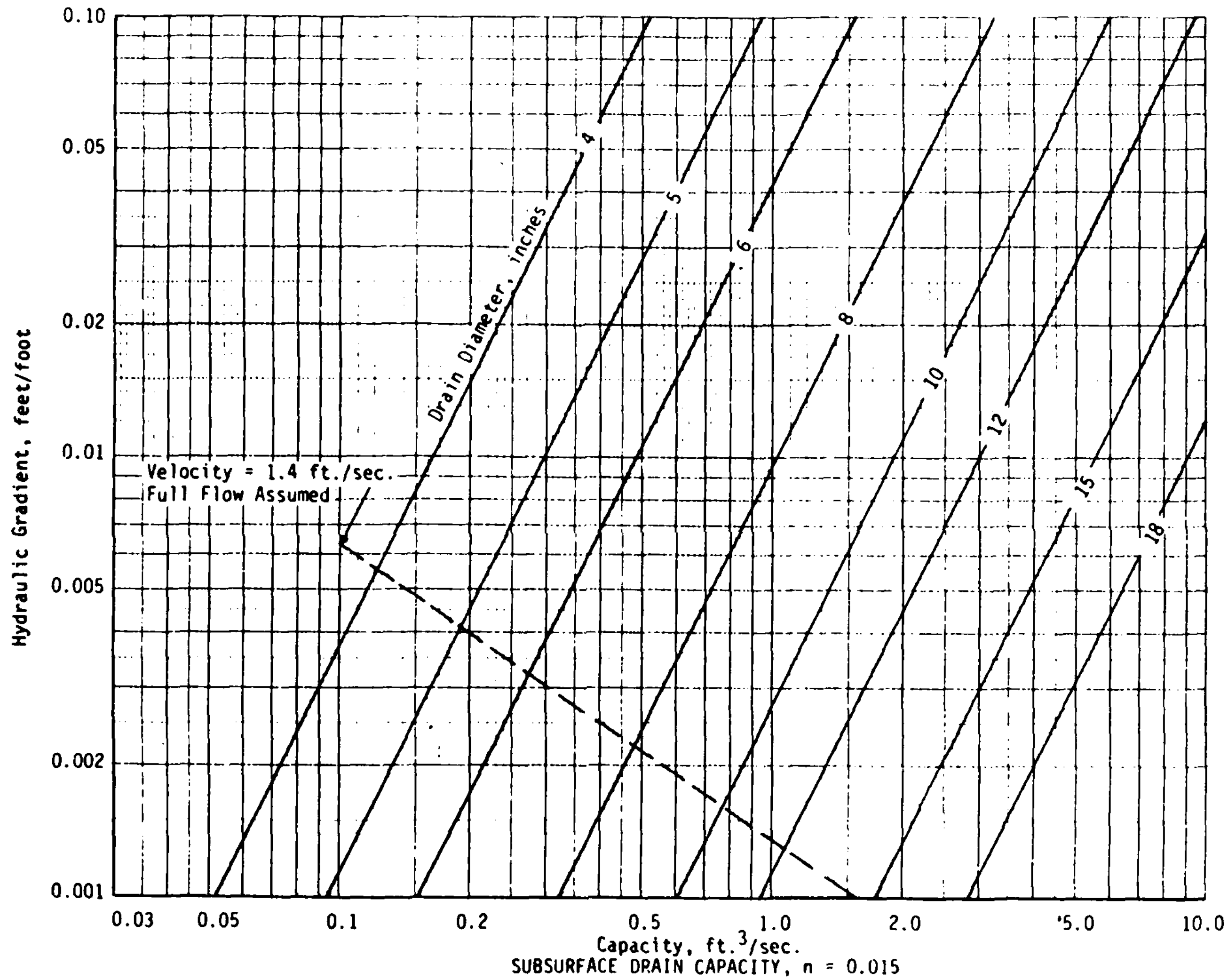

Figure D-46. Subsurface drain capacity, n = 0.015 (USDA, SCS 1971)

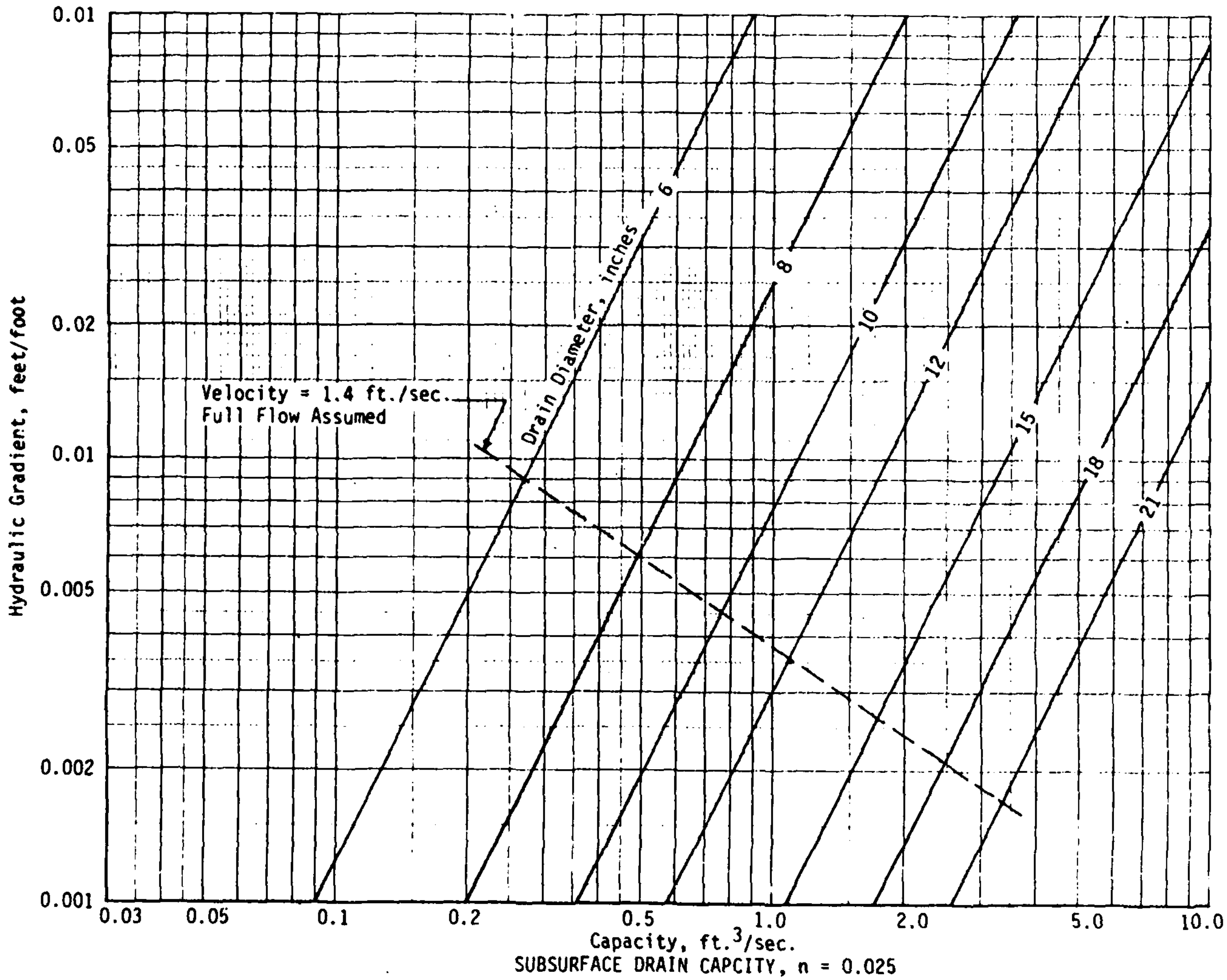

Figure D-47. Subsurface drain capacity, n = 0.025 (USDA, SCS 1971)

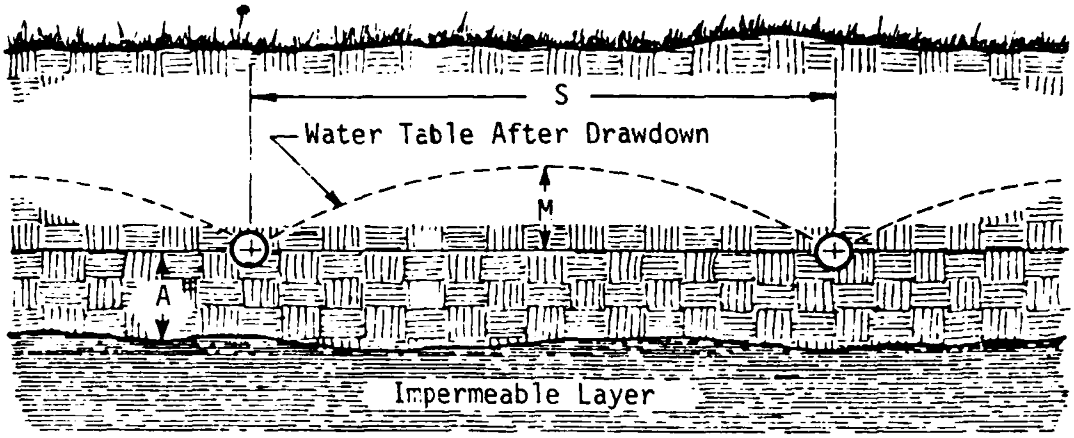

Figure D-48. Relief drain spacing (USDA, SCS 1971)

From the specifications, the drains must remove 1 in. of water in 24 hr or 0.042 ft^3/sec/acre.

$$0.042 \text{ ft}^3\text{/sec/acre} \times 0.57 \text{ acre} = 0.02 \text{ ft}^3\text{/sec}$$

From Table D-13, $n = 0.013$ for bituminized fiber pipe.

From Figure D-46, a 4-in. pipe must be used for the laterals.

The first 25 ft of the main will drain 25 ft on either side of the pipe. The remaining 375 ft will drain only 25 ft on the side opposite from the laterals. In addition, the main will drain the laterals.

Drainage from main:

$$\frac{25 \text{ ft} \times 50 \text{ ft}}{43{,}560 \text{ ft}^2\text{/acre}} + \frac{375 \text{ ft} \times 25 \text{ ft}}{43{,}560 \text{ ft}^2\text{/acre}} = 0.24 \text{ acre}$$

Drainage from laterals:

$$8 \times 0.57 \text{ acre} = 4.56 \text{ acres}$$

$$\text{Total} = 0.24 + 4.56 = 4.8 \text{ acres}$$

Required capacity:

$$0.042 \text{ ft}^3/\text{sec/acre} \times 4.8 \text{ acre} = 0.20 \text{ ft}^3/\text{sec}$$

From Figure D-46, choose a 5-in. pipe for the main.

Spacing of relief drains

232. If the necessary information is known, the following equation and Figure D-48 can be used to calculate drain spacing in lieu of the recommended standard:

$$S = \frac{\sqrt{4k\ (M2 + 2\ AM)}}{q}$$

where

S = drain spacing, ft

k = average hydraulic conductivity, in./hr (for practical purposes, hydraulic conductivity is equal to permeability)

M = vertical distance, after drawdown, of water table above drain at mid-point between lines, ft

A = depth of barrier below drain, ft

q = drainage coefficient, rate of water removal, in./hr

Limitations of the equation are listed in the SCS National Engineering Handbook, Section 16, Drainage of Agricultural land (USDA, SCS 1971)

Spacing of interceptor drains

233. If one interceptor drain is not sufficient, the spacing of multiple drains can be calculated by the following equation:

$$Le = \frac{ki}{q}\ (de - dw + W_2)$$

where

Le = the distance downslope from the drain to the point where the water table is at the desired depth after drainage, ft. The second drain should be located at this point

k = the average hydraulic conductivity of the subsurface profile to the depth of the drain, in./hr

q = drainage coefficient, rate of water removal, in./hr

i = the hydraulic gradient of the water table before drainage, ft/ft

de = the effective depth of the drain, ft

dw = the desired minimum depth to water table after drainage, ft

W_2 = the distance from the ground surface to the water table, before drainage, at the distance (Le) downslope from the drain, ft

Also, see Figure D-49. Further information on this equation can be obtained from the SCS National Engineering Handbook, Section 16, Drainage of Agricultural Land (USDA, SCS 1971).

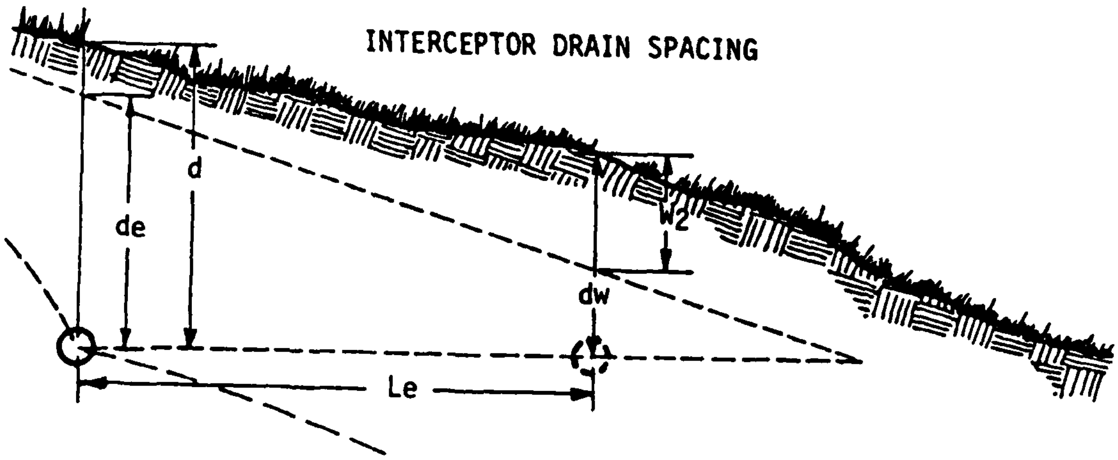

Figure D-49. Interceptor drain spacing (USDA, SCS 1971)

WATERSPREADING

234. Waterspreading is the diverting of runoff from natural channels or gullies by means of a system of dams, dikes, or ditches and spreading it over relatively flat areas (Figure D-50).

235. The purpose of waterspreading is to provide extra moisture for improved vegetative cover and to disperse floodwaters to reduce sediments and damage to watershed areas.

Applicability

236. This practice applies to locations where climate, topography, soils, and runoff conditions are suitable for installation and operation of a waterspreading system. This is a practice with limited application.

Planning Considerations

237. The topography of the spreading area should be relatively flat, smooth, and free of gullies or channels that would tend to concentrate the spread waters. Soils should have a moderate to high water-holding capacity. The combination of soils, slopes, and plant cover should be such that spreading of floodwaters will not create erosion problems. Sites without adequate plant cover should be properly revegetated.

238. A well-sodded area, or a wooded or brush-covered site, can be used without alteration. If such sites are not available, artificial spreading structures may be used instead. Trees and brush should be planted to supplant the artificial structures.

239. Spreading structures may be constructed of any of the materials commonly used on erosion control projects. Where the amount of runoff is small, wire-netting fences, brush, logs, or loose rock may be used. For flows exceeding about 10 cfs, the spreading structures must be substantially built of masonry or concrete. After the large stream has been broken up into smaller units, the lighter types of spreading structures may be used.

240. Figure D-50 shows a spreading structure which includes an earth dike with multiple outlets protected with brush or rock for large flows, and a typical system of wire-netting spreaders below a diversion ditch.

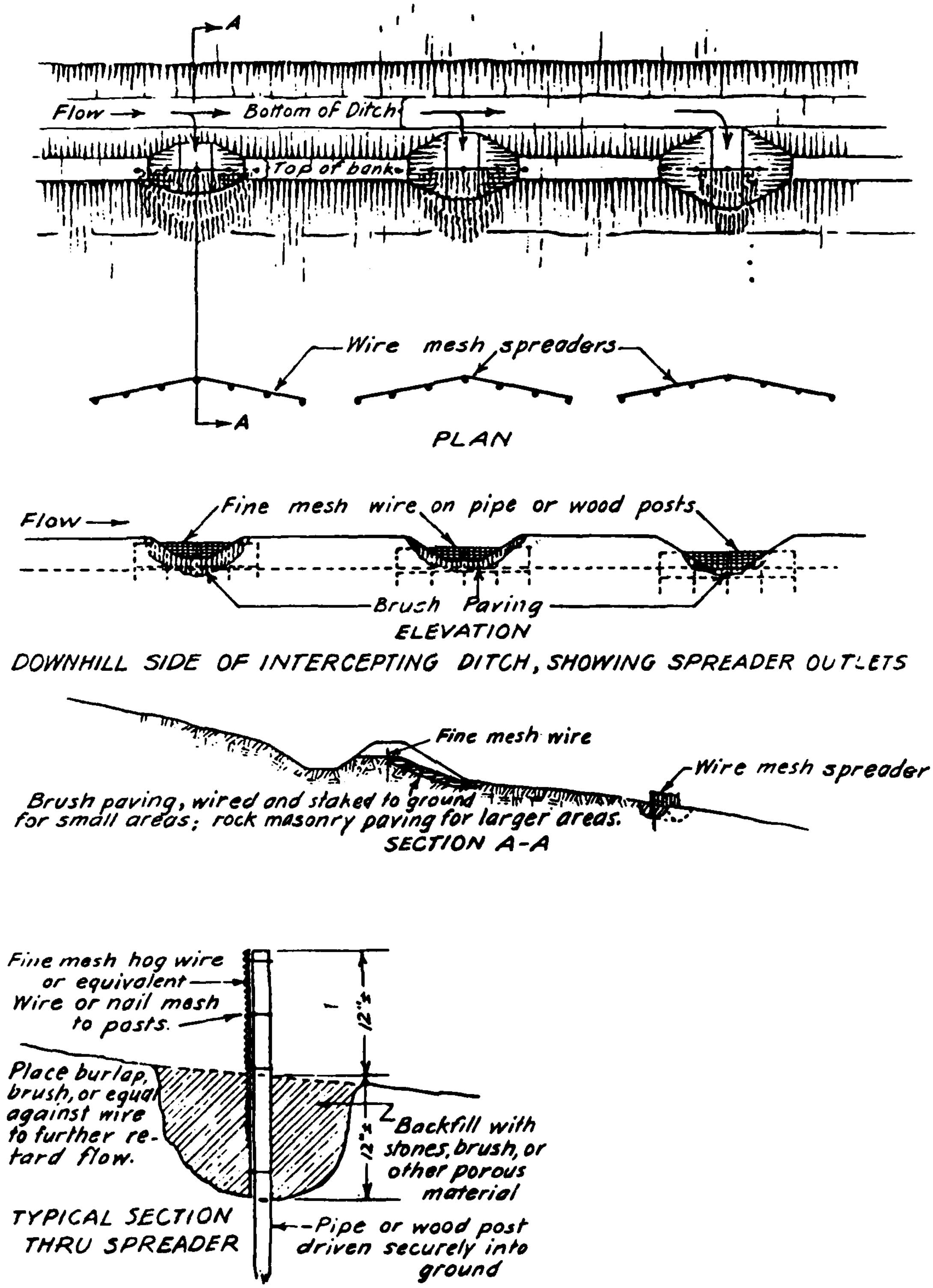

Figure D-50. Spreading structure details
(USDA, Forest Service 1974)

241. To distribute the flow from a diversion or intercepting ditch, screened openings in the downhill side of the ditch can be arranged to release only part of the flow from each opening, to give as widespread distribution as possible. In Figure D-50, the first opening reaches only halfway to the ditch bottom, the second one three fourths of the way, and the last one is on the same level as the ditch bottom. The number and depth of the outlets will vary, depending on the amount of flow, the ground slope, and the infiltration capacity of the soil.

242. The wire-mesh spreaders are built in a flat V-shape with the point of the V in line with the greatest flow. The angle of the V should be such that the ground slope along the wings is not steeper than 1 percent. As a general rule, the spreading should be done only on areas where there is a good sod cover to prevent erosion.

243. The spreader wire should be a close diamond pattern or equivalent, preferably 24 in. wide for the larger areas and 18 in. for the others. One half of the width is buried in a trench which is backfilled with stones, gravel, brush, or other porous material. The effectiveness of the barriers can be increased by weaving brush, straw, etc., into the wire.

244. After installation, the spreading areas should be inspected occasionally to determine the need for aintenance or additional corrective measures. Waterspreading systems should be inspected prior to the runoff season and repaired as needed for proper function.

WATERWAYS

245. A waterway is a permanent, designed storm water conveyance channel, shaped and lined with appropriate vegetation or structural material to safely convey excess storm water runoff. Its purpose is to provide for the disposal of concentrated surface runoff water without damage from erosion.

Applicability

246. This practice is generally applicable to man-made channels, including roadside ditches, and intermittent natural channels that are modified to accommodate increased flows generated by land disturbance. This practice is not generally applicable to major, continuous flowing natural streams.

Planning Considerations

247. The design of a waterway primarily encompasses the design of the channel cross section and lining, as well as the vertical and horizontal alignment. The primary consideration in this design is the volume and the velocity of flow expected in the channel. Secondary considerations include land availability, compatibility with land use and surrounding environment, safety, maintenance requirements, outlet conditions, etc.

Design Criteria

Capacity

248. Unless otherwise specified in local or state drainage criteria,* all channels should be designed to contain at least the peak flow from a 10-year frequency storm. Where the consequences of channel flooding are "severe," the capacity of the channel should be increased accordingly. This requirement for confinement may be waived on slopes of less than 1 percent where out-of-bank flow will not cause erosion or property damage.

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* Many state drainage criteria require design for a 10-year frequency storm or greater.

Velocity

249. Channels should be designed so that the velocity of flow expected from the design storm will not exceed the permissible velocity or tractive force for the type of lining used.

Grass-lined channels

250. Permissible velocities for grass-lined channels are shown in Table D-14.

Riprap-lined channels

251. Riprap linings can be designed to withstand most flow velocities by choosing a stable stone size. The procedure for selecting a stable stone size for channels is contained in Riprap.

Table D-14

Permissible Velocities For Vegetated Channels*

	Permissible Velocity, fps					
	Erosion Resistant Soils % Slope			Easily Eroded Soils % Slope		
Cover	0-5	5-10	Over 10	05	5-10	Over-10
Bermudagrass	8	7	6	6	5	4
Buffalo grass Kentucky bluegrass Smooth brome Blue grama Tall fescue Reed canarygrass	7	6	5	5	4	3
Lespedeza sericea Weeping lovegrass Alfalfa Crabgrass Redtop Red fescue	3.5	NR	NR	2.5	NR	NR
Grass mixture	5	4	NR	4	3	NR
Annuals for temporary protection	3.5	NR	NR	2.5	NR	NR

* Adapted from Haan and Barfield (1978) and Virginia Soil and Water Conservation Commission (1980). NR Not recommended.

Concrete-lined channels

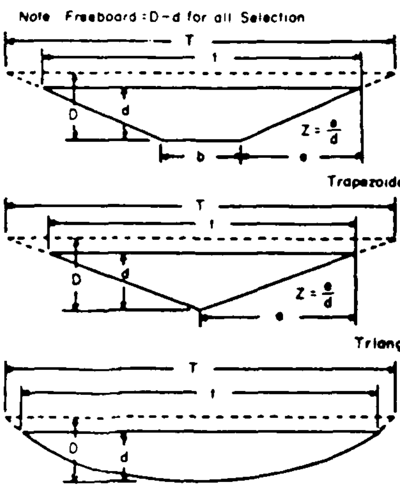
252. Velocity is usually not a limiting factor in the design of concrete-lined channels; however, it should be kept in mind that the flow velocity at the outlet of the paved section must not exceed the permissible velocity of the receiving channel.

Depth

253. The design water surface elevation of a channel receiving water from diversions or other tributary channels should be equal to or less than the design water surface elevation of the diversion or other tributary channel at the point of intersection.

Cross sections

254. Channel cross sections may be vee-shaped, parabolic, or trapezoidal. Properties of typical channel cross sections are shown in Figure D-51.



Cross-Sectional Area a	Wetted Perimeter, p	Hydraulic Radius $R = \frac{a}{p}$	Top Width
$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2+1}}$	$t = b + 2dZ$ $T = b + 2DZ$
Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z+1}}$ or $\frac{d}{2}$ approx.	$t = 2dZ$ $T = \frac{D}{d}t$
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2d}{1.5t^2 + 4d^2}$ or $\frac{2d}{3}$ approx.	$t = \frac{a}{0.67d}$ $T = t\left(\frac{D}{d}\right)^{1/2}$

Figure D-51. Properties of typical channel cross sections (Haan and Barfield 1978)

255. The top width of parabolic and vee-shaped, grass-lined channels should not exceed 30 ft, and the bottom width of trapezoidal, grass-lined channels should not exceed 15 ft unless multiple or divided waterways, riprap center, or other means are provided to control meandering of low flows.

256. Some states have limited dimensions with regard to the top width of parabolic and vee-shaped, grass-lined channels and the bottom width of trapezoidal, grass-lined channels. Under normal conditions, the channels should be designed according to standard engineering practice.

From Figure D-57 for $Vr = 3.25$ and D retardance, $n = 0.04$

$$V = \frac{1.486}{n} r^{2/3} s^{1/2} \quad \text{(Manning's equation)}$$

where n is the roughness coefficient, r is the hydraulic radius, and s is the hydraulic gradient.

$$V = \frac{1.486}{0.04} (0.65^{2/3})(0.03^{1/2}) = 4.83 \text{ fps}$$

This is acceptable, but is less than V_{max}. Therefore, try a slightly smaller channel.

Bottom width = 10 feet

$$11 = 10D + 3D^2$$
$$D = 0.87 \text{ ft}$$

$$r = 0.71$$

$$Vr = 3.55$$

$n = 0.04$ (see Figure D-57)

$$V = \frac{1.486}{n} r^{2/3} s^{1/2} = 5.15 \text{ which is greater than } V$$

Therefore, select design bottom width = 12 ft

Velocity = 4.83 fps for D retardance

Depth = 0.8 ft

Step 2 - Capacity (C retardance). Determine additional depth needed to offset the increased retardance and decrease velocity.

Try $D = 0.9$ ft

$$A = (12)(0.9) + 3(0.9^2) = 13.23$$

$$r = \frac{A}{P} = \frac{13.23}{12 + 2\ (0.9)\sqrt{3^2 + 1}} = 0.75$$

Assume $V = 4.4$ fps

$$Vr = (4.4)(0.75) = 3.30$$

For $Vr = 3.30$ and C retardance, $n = 0.046$ (Figure D-57)

Step 1 - Stability - D curve retardance

$Q = 55$ cfs

$V_{max} = 5$ fps

$$A = \frac{Q}{V_{max}} = \frac{55}{5} = 11 \text{ ft}^2$$

Try Bottom Width (b) = 12 ft

$$A = bD + zD^2$$

$$11 = 12D + 3D^2$$

Solve for D by use of the quadratic equation.

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$D = \frac{-12 \pm \sqrt{12^2 - 4(3)(11)}}{2(3)}$$

$$= \frac{-12 + 16.61}{6} = \frac{4.61}{6}$$

$$= 0.77 \text{ ft}$$

Hydraulic Radius

$$r = \frac{\text{area (A)}}{\text{wetted perimeter (P)}} = \frac{bd + zD^2}{b + 2D\sqrt{z^2 + 1}}$$

$$r = \frac{12\ (0.77) + 3\ (0.77^2)}{12 + 2(0.77)\ \sqrt{3^2 + 1}}$$

$$r = \frac{9.24 + 1.78}{12 + 4.87}$$

$$r = \frac{11.02}{16.87} = 0.65$$

$$Vr = 5(0.65) = 3.25$$

with the requirement for nonerosive velocity when vegetation is short (D retardance) and for capacity when vegetation is tall (C retardance).

Problem 2

275. Determine the nonerosive velocity and dimensions for a waterway with trapezoidal cross section.

Given:

Runoff	Q	= 55 cfs
Grade		= 2.0 percent
Side slopes		= 2.1
Vegetative cover		= Kentucky bluegrass

Condition of vegetation

Good stand-headed (6 in. - 12 in.)	= C curve retardance (see Table D-16)
Permissible velocity	= 5 fps (see Table D-14)

Solution: Use the Trapezoidal Channel Design Table for the Grade 2.0 percent (Table D-18). Horizontally opposite 55 cfs and under the column headed b = 6 ft, find D = 1.3 ft, and V = 4.9 fps.

276. Therefore, a waterway with trapezoidal cross section, 2:1 side slope, bottom width of 6 ft, and a depth of 1.3 ft will carry 55 cfs at a maximum velocity of 4.9 fps for C curve retardance.

Problem 3

277. Determine the safe velocity and dimensions for a waterway with trapezoidal cross section that does not fit the Trapezoidal Channel Design Tables.

Given:

Runoff	Q	= 55 cfs
Grade		= 3.0 percent side slope
Vegetative cover		= Kentucky bluegrass

Condition of vegetation

Good stand-mowed (3 in. 4 in.)	= D curve retardance (see Table D-16)
Good stand-headed (6 in. - 12 in.)	= C curve retardance (see Table D-16)
Permissible velocity	= 5 fps (see Table D-14)

Solution: The solution is a trial and error process. The first step is to design for stability when the vegetation is short (D retardance) and the second step is to design for capacity when the vegetation is tall (C retardance).

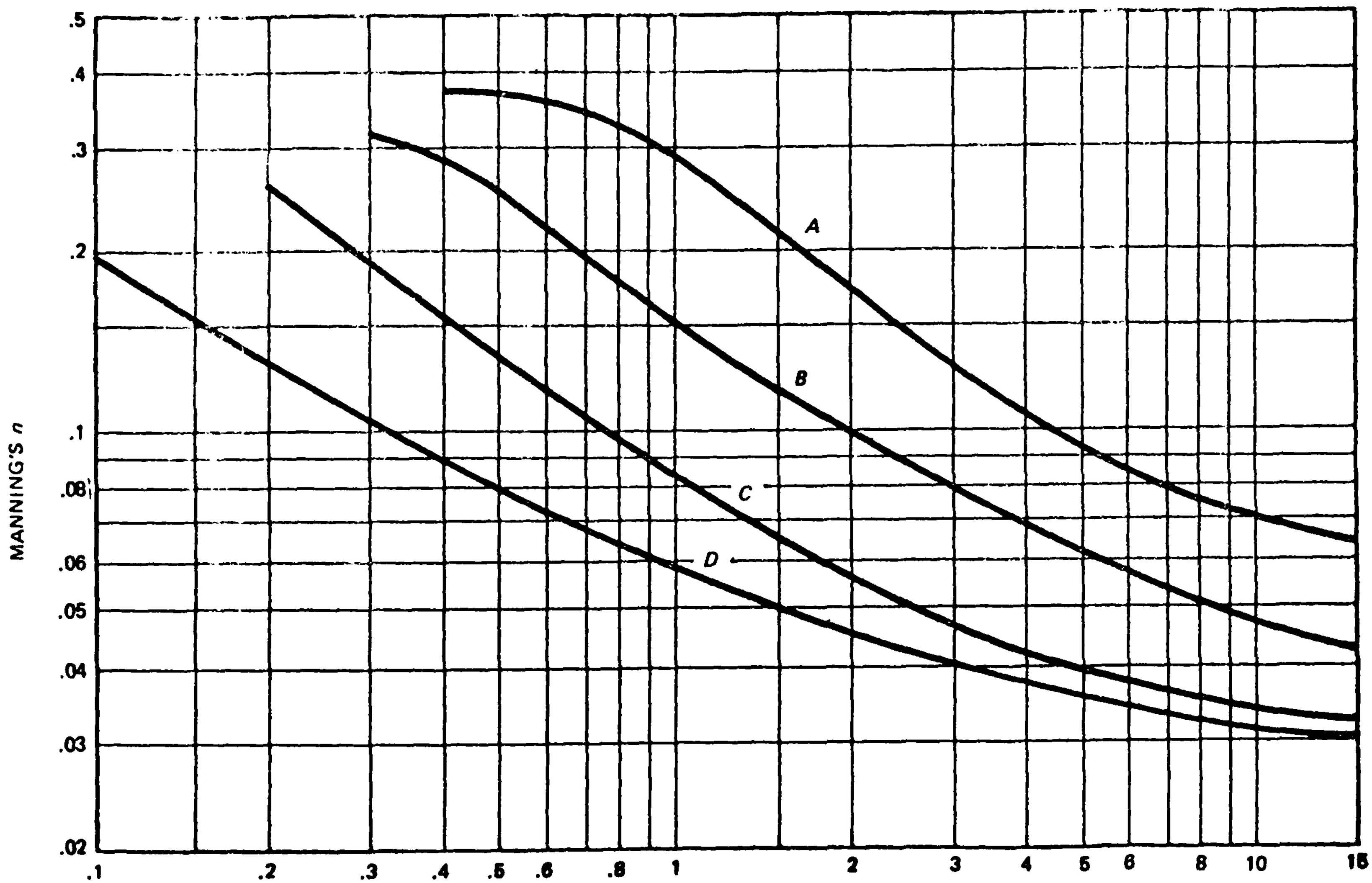


Figure D-57. Manning's n related to velocity, hydraulic radius, and vegetal retardance (USEPA 1976)

Table D-18

Trapezoidal Channel Design for Grade 2.0 Percent

(USEPA 1976)

Q	b = 2		b = 4		b = 6		b = 8		b = 10		b = 12		b = 14		b = 16	
cfs	D	V	D	V	D	V	D	V	D	V	D	V	D	V	D	V
15	1.2	3.0	0.9	2.7	0.8	2.4	0.7	2.1	0.7	1.9	0.7	1.7	0.6	1.6	0.6	1.4
20	1.3	3.4	1.0	3.2	0.9	2.9	0.8	2.6	0.7	2.3	0.7	2.1	0.7	1.0	0.6	1.8
25	1.4	3.8	1.1	3.6	1.0	3.3	0.9	3.0	0.8	2.7	0.7	2.5	0.7	2.3	0.7	2.1
30	1.5	4.2	1.2	3.9	1.0	3.6	0.9	3.3	0.8	3.1	0.8	2.8	0.7	2.6	0.7	2.4
35	1.6	4.4	1.3	4.2	1.1	3.9	1.0	3.6	0.9	3.3	0.8	3.1	0.8	2.9	0.7	2.7
40	1.6	4.7	1.3	4.5	1.1	4.2	1.0	3.9	0.9	3.6	0.9	3.4	0.8	3.1	0.8	2.9
45	1.7	4.9	1.4	4.7	1.2	4.5	1.1	4.2	1.0	3.9	0.9	3.6	0.8	3.4	0.8	3.2
50	1.8	5.2	1.5	5.0	1.2	4.7	1.1	4.4	1.0	4.1	0.9	3.9	0.9	3.6	0.8	3.4
55	1.8	5.4	1.5	5.1	1.3	4.9	1.2	4.6	1.0	4.3	1.0	4.0	0.9	3.8	0.9	3.6
60	1.9	5.5	1.6	5.3	1.4	5.1	1.2	4.8	1.1	4.5	1.0	4.2	0.9	4.0	0.9	3.8
65	1.9	5.7	1.6	5.5	1.4	5.3	1.2	5.0	1.1	4.7	1.0	4.4	1.0	4.2	0.9	4.0
70	2.0	5.9	1.7	5.7	1.4	5.5	1.3	5.2	1.2	4.9	1.1	4.6	1.0	4.3	1.0	4.1
75			1.7	5.9	1.5	5.6	1.3	5.3	1.2	5.0	1.1	4.7	1.0	4.5	1.0	4.3
80					1.5	5.8	1.4	5.5	1.2	5.2	1.1	4.9	1.1	4.7	1.0	4.4
90							1.4	5.8	1.3	5.5	1.2	5.2	1.1	5.0	1.1	4.7
100									1.4	5.8	1.3	5.5	1.2	5.2	1.1	5.0
110									1.4	6.0	1.3	5.8	1.2	5.5	1.1	5.2
120											1.4	6.0	1.3	5.7	1.2	5.4
130													1.3	5.9	1.2	5.7
140															1.3	5.9

Note: C Retardance; Side Slope = 2:1. Q = flow, cubic feet per second, V = velocity, feet per second, b = bottom width, feet, D = depth, feet.

Table D-17

Parabolic Waterway Design for Grade 5.0

Q	V = 2.0		V = 2.5		V = 3.0		V = 3.5		V = 4.0		V = 4.5		V = 5.0		V = 5.5		V = 6.0	
cfs	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D
15	29	0.6	21	0.6	15	0.7	12	0.7	9	0.8	7	0.8	6	0.9	5	1.0		
20	39	0.6	28	0.7	20	0.7	16	0.7	12	0.8	10	0.8	8	0.9	6	1.0	5	1.1
25	49	0.6	35	0.6	25	0.7	20	0.7	15	0.8	12	0.8	10	0.9	8	1.0	7	1.0
30	58	0.6	42	0.6	30	0.7	24	0.7	18	0.8	14	0.8	11	0.9	9	1.0	8	1.0
35	68	0.6	49	0.6	35	0.7	28	0.7	21	0.8	17	0.8	13	0.9	11	0.9	9	1.0
40	77	0.6	56	0.6	40	0.7	32	0.7	24	0.8	19	0.8	15	0.9	12	0.9	10	1.0
45	86	0.6	63	0.7	44	0.7	36	0.7	27	0.8	21	0.8	17	0.9	14	0.9	12	1.0
50	96	0.6	69	0.6	49	0.7	40	0.7	30	0.8	24	0.8	19	0.9	15	0.9	13	1.0
55	105	0.6	76	0.6	54	0.7	44	0.7	33	0.8	26	0.8	21	0.9	17	0.9	14	1.0
60	114	0.6	83	0.6	59	0.7	48	0.7	36	0.8	28	0.8	22	0.9	18	0.9	15	1.0
65	123	0.6	89	0.6	63	0.7	52	0.7	38	0.8	31	0.8	24	0.9	19	0.9	17	1.0
70	132	0.6	96	0.6	68	0.7	56	0.7	41	0.8	33	0.8	26	0.9	21	0.9	18	1.0
75	142	0.6	102	0.7	73	0.7	59	0.7	44	0.8	35	0.8	28	0.9	22	0.9	19	1.0
80	151	0.6	109	0.6	78	0.7	63	0.7	47	0.8	37	0.8	30	0.9	24	0.9	20	1.0
90	169	0.6	122	0.6	87	0.7	71	0.7	53	0.8	42	0.8	33	0.9	27	0.9	23	1.0
100	187	0.6	136	0.6	97	0.7	79	0.7	59	0.8	47	0.8	37	0.9	30	0.9	26	1.0
110	205	0.6	149	0.6	106	0.7	86	0.7	64	0.8	51	0.8	41	0.9	33	0.9	28	1.0
120	223	0.6	162	0.6	115	0.7	94	0.7	70	0.8	56	0.8	44	0.9	35	0.9	31	1.0
130	241	0.6	175	0.6	125	0.7	102	0.7	76	0.8	60	0.8	48	0.9	38	0.9	33	1.0
140	259	0.6	188	0.6	134	0.7	109	0.7	81	0.8	65	0.8	52	0.9	41	0.9	36	1.0
150	276	0.6	201	0.6	143	0.7	117	0.7	87	0.8	69	0.8	55	0.9	44	0.9	38	1.0
160	294	0.6	213	0.6	152	0.7	124	0.7	93	0.8	74	0.8	59	0.9	47	0.9	40	1.0
170	311	0.6	226	0.6	162	0.7	132	0.7	98	0.8	78	0.8	62	0.9	50	0.9	43	1.0
180	329	0.6	239	0.6	171	0.7	139	0.7	104	0.8	83	0.8	66	0.9	53	0.9	45	1.0

Note: V for Retardance D; T and D for Retardance C. Q = flow in cubic feet per second, V = velocity in feet per second, T = top width in feet, D = depth in feet.

Table D-16

Classification of Vegetal Cover in Waterways Based on Degree of Flow Retardance by the Vegetation (USEPA 1976)

Cover	Stand	Condition and Height	Retardance
Red canarygrass	Excellent	Tall (average 36 in.)	A
Kentucky 31 tall fescue	Excellent	Tall (average 36 in.)	
Tufcote, Midland, and Coastal bermudagrass	Good	Tall (average 12 in.)	B
Reed canarygrass	Good	Mowed (average 12 to 15 in.)	
Kentucky 31 tall fescue	Good	Unmowed (average 18 in.)	
Red fescue	Good	Unmowed (average 16 in.)	
Kentucky bluegrass	Good	Unmowed (average 16 in.)	
Redtop	Good	Average	
Kentucky bluegrass	Good	Headed (6 to 12 in)	C
Red fescue	Good	Headed (6 to 12 in.)	
Tufcote, Midland, and Coastal bermudagrass	Good	Mowed (average 6 in.)	
Redtop	Good	Headed (15 to 20 in.)	
Tufcote, Midland, and Coastal bermudagrass	Good	Mowed (2-1/2 in.)	D
Red fescue	Good	Mowed (2-1/2 in.)	
Kentucky bluegrass	Good	Mowed (2 to 5 in.)	

Design Procedures

272. The following are used to design grassed waterways:

a. Classification of vegetal cover based on degree of flow retardance by the vegetation (Table D-16).

b. Parabolic Waterway Design Tables for various grades, velocities, top width and depth, and retardances (for grade 5.0 percent, see Table D-17).

c. Trapezoidal Channel Design Tables for various grades, velocities, depths, and retardances (for grade 2.0 percent, see Table D-18).

d. Manning's n related to velocity, hydraulic radius, and vegetal retardance (Figure D-57).

The use of these can best be shown by sample problems, which follow.

Sample Problems

Problem 1

273. Determine the nonerosive velocity and dimensions for stability and capacity for a waterway with parabolic cross section.

Given:	Runoff	Q = 55 cfs
	Grade	= 5.1 percent
	Vegetative cover	= Kentucky bluegrass
	Condition of vegetation	
	Good stand-mowed (3 in. - 4 in.)	= D curve retardance (see Table D-16)
	Good stand-headed (6 in. - 12 in.)	= C curve retardance (see Table D-16)
	Permissible velocity	= 4 fps (see Table D-14)

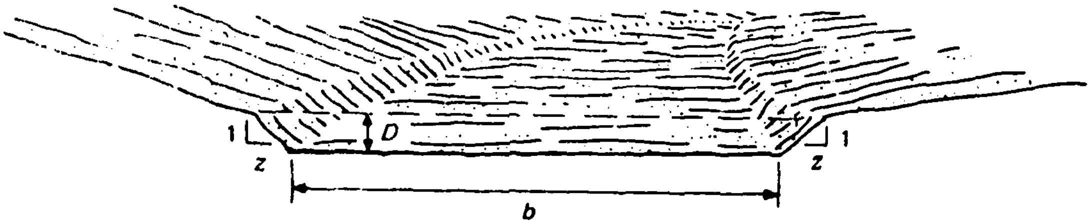
Solution: Use the Parabolic Waterway Design Table for the grade nearest 5.1 percent (for grade 5.0 percent, see Table D-17). Horizontally opposite 55 cfs and under the columns headed V = 4.0 fps, find T = 33 ft, and D = 0.8 ft.

274. Therefore, a waterway with parabolic cross section, a top width of 33 ft, and a depth of 0.8 ft will carry 55 cfs at a maximum velocity of 4 fps when the vegetative lining is short (3 to 4 in. in height). This complies

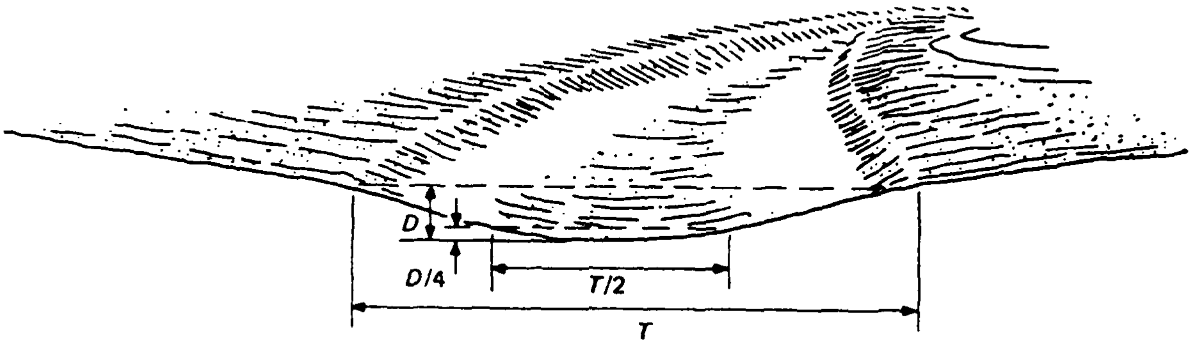
Table D-15

Grass Establishment Alternatives (VSWCC 1980)

Establishment Technique	Conditions	Remarks
1. (a) Seeding with straw mulch and tack coat	1. Slopes less than 10-15% 2. Velocity less than 3 fps 3. Majority of drainage cannot be diverted away from channel during germination and establishment 4. Erosion-resistant soils	1. (a) See permanent seeding for seeding requirements. When mulching, use 2 tons/acre small grain straw with an acceptable tacking agent. Refer to Table D-16 for more information.
(b) Establishing bermudagrass by sprigging		(b) See Sprigging and Tubeling for bermudagrass establishment. Irrigation water must be available during the first 4 weeks. Divert drainage away from the channel during the first 3 weeks of the establishment period by using temporary dikes, silt fencing, or straw bale barriers.
2. Seeding with straw mulch and jute mesh or erosion netting	1. Slopes less than 10-15% 2. Velocity less than 5 fps 3. Majority of drainage cannot be diverted away from channel during germination and establishment 4. Moderately erodible soil	2. In addition to 1.(a) above, straw mulch should be secure with netting. If using jute mesh, use only 1 ton/acre small grain straw, evenly distributed. If using a light plastic or paper erosion netting, 1-1/2 to 2 tons/acre of straw is appropriate. Excelsior blankets, used alone, are also acceptable mulches for waterways.
3. Sodding	1. Slopes greater than 10-15% 2. Velocity between 5 and 6 fps 3. Majority of drainage cannot be diverted away from channel during germination 4. Highly erodible soil	3. See Sodding for soil installation requirements.



Trapezoidal cross section



Parabolic cross section

Construction Specifications

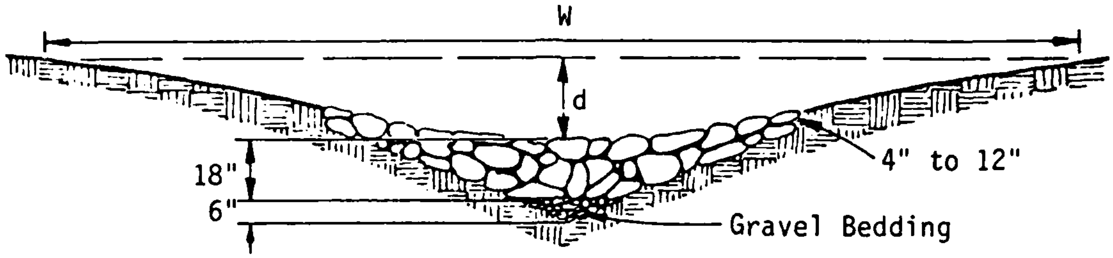
1. All trees, brush, stumps, roots, obstructions, and other unsuitable material should be removed and properly disposed of.

2. The channel should be excavated or shaped to the proper grade and cross section.

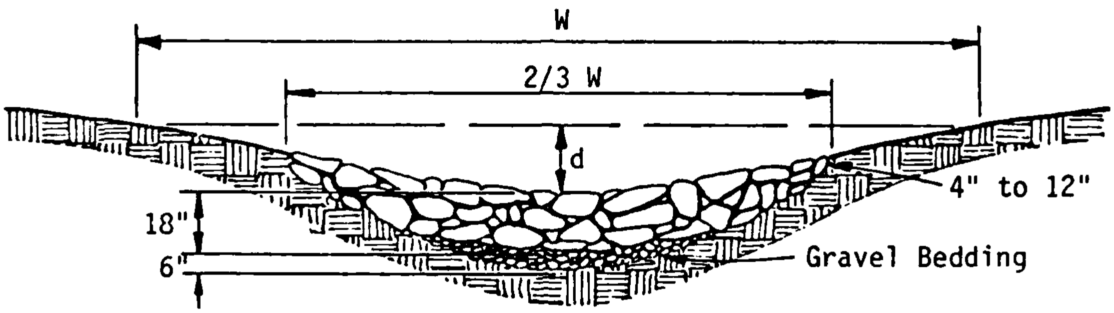
3. All fills should be well compacted to prevent unequal settlement.

4. Any excess soil should be removed and properly disposed of.

Figure D-56. Grassed waterway (USEPA 1976, VSWCC 1980)



V-Shaped Waterway with Stone Center Drain
(Shaped by Motor Patrol)



Parabolic-Shaped Waterway with Stone Center Drain
(Shaped by Bulldozer)

Figure D-55. Stone-lined waterways (USDA, SCS 1978)

269. Consult Table D-15 to choose the correct grass establishment technique. For each establishment technique, if any one of the four conditions is exceeded, then consider concrete- or riprap-lined channels.

Concrete-lined channels

270. Concrete-lined channels must be constructed in accordance with all applicable state specifications. These generally include:

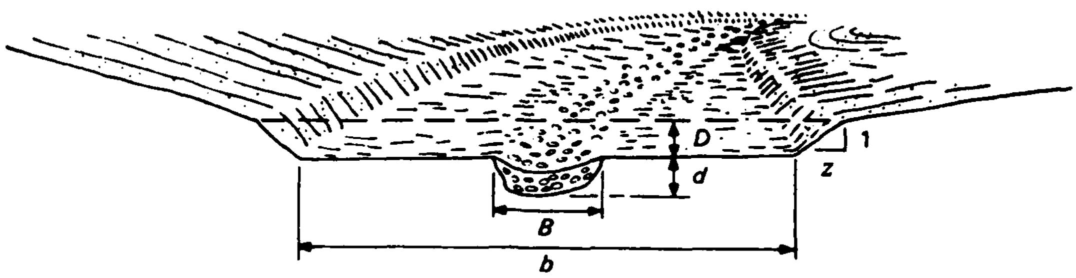
a. The subgrade should be moist when pouring concrete.

b. Traverse joints for crack control should be provided at approximately 20-ft intervals and when more than 45 min elapses between the times of consecutive concrete placements. All sections should be at least 6 ft long. Crack control joints may be formed by using a 1/8-in.-thick removal template, by scoring or sawing to a depth of at least 3/4 in., or by an approved "leave in" type insert.

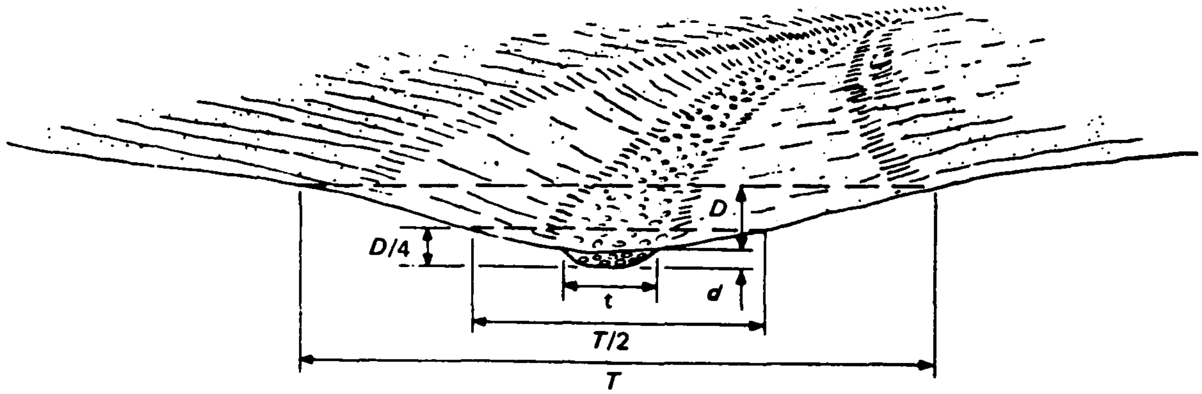
c. Expansion joints should be installed every 100 ft.

Riprap-lined channels

271. See Riprap for installation requirements.



Trapezoidal cross section



Parabolic cross section

Figure D-54. Grassed waterway with stone center
(USEPA 1976, VSWCC 1980)

267. Subsurface drains should be constructed to handle base flow. Should the waterway or channel have a stone center for base flow, the base flow portion can be stabilized with riprap. Gabion mattress channel liners may also be used for base flow in addition to or instead of stone centers and/or subsurface drains. Gabion mattress channel liners may also be used for design flow.

Grass-lined channels (Figure D-56)

268. The method used to establish grass in the ditch or channel will depend upon the severity of the conditions encountered. The methods available for grass establishment are:

a. Seeding with straw mulch and tack coat. Sprigging with bermudagrass.

b. Seeding with straw mulch and jute mesh or erosion netting.

c. Sodding.

Figure D-53. Trapezoidal channel

requirements, etc. The vegetation should have a dense root system and be water-tolerant.

262. Riprap. Riprap should meet the design criteria set forth in Riprap.

263. Concrete. Concrete channels should be at least 4 in. thick and meet applicable criteria.

Drainage (grass-lined channels)

264. Any base flow should be handled by a stone center (Figure D-54), subsurface drain, or other suitable means, since sustained wetness usually prevents adequate vegetative cover. The cross-sectional area of the stone center or subsurface drain to be provided should be determined by using the US Geological Survey base flow rate or by actual measurement of the maximum base flow. Figure D-55 shows typical cross sections for stone center channels. Refer to Riprap for the correct stone size. It should be remembered that riprap sizes should be determined based on flow depths expected during the design storm and not for base flow conditions.

265. Subsurface drainage measures should be provided for sites having high water tables or seepage problems, except where water-tolerant vegetation, such as reed canarygrass, can be used.

Outlets

266. Every waterway should have a stable outlet. This outlet may be another waterway, a stabilized open channel, grade stabilization structure, etc. In all cases, the outlet must discharge in such a manner as not to cause erosion. Outlets must be constructed and stabilized before operating the waterway.

Vee-shaped (triangular) ditches

257. Vee-shaped ditches are generally used where the quantity of water to be handled is relatively small, such as along roadsides. A grass or sod lining will suffice where velocities in the ditch are low. For steeper slopes where high velocities are encountered, a concrete or bituminous concrete lining may be appropriate.

Parabolic channels

258. Parabolic channels (Figure D-52) are often used where the quantity of water to be handled is larger and where space is available for a wide, shallow channel with low velocity flow. Riprap should be used where higher velocities are expected and where some dissipation of energy (velocity) is desired. Combinations of grass and riprap are also useful where there is a continuous low flow in the channel.

Figure D-52. Parabolic channel

Trapezoidal channels

259. Trapezoidal channels (Figure D-53) are often used where the quantity of water to be carried is large and conditions require that it be carried at a relatively high velocity. Trapezoidal ditches are generally lined with concrete or riprap.

260. Outlet conditions for all channels are very important, especially at the transition from a man-made lining such as concrete to a vegetative lining. Appropriate measures must be taken to dissipate the energy of the flow to prevent scour of the receiving channel (see Outlet Protection).

Channel linings

261. Grass. The grass type used should be appropriate for the site conditions, i.e., drainage tolerance, shade tolerance, maintenance

$$V = \frac{1.486}{0.046} (0.75^{2/3})(0.03^{1/2}) = 4.62 \text{ fps}$$

Since 4.62 fps is greater than the assumed
V, assume V = 4.6 fps

Vr = (4.6)(0.75) = 3.45

n = 0.046 (Figure D-57)

$$V = \frac{1.486}{0.046} (0.75^{2/3})(0.03^{1/2}) = 4.62 \text{ fps}$$

This is close enough.

Therefore, dimensions and velocities are as follows:

Bottom width = 12 ft

Side slopes = 3:1

For D retardance V = 4.83 fps
D = 0.8 ft

For C retardance V = 4.62 fps
D = 0.9 ft

Maintenance

Grass-lined channels

278. During the initial establishment of grass-lined channels, any repairs and grass establishment should be done immediately. After grass has become established, the channel should be checked periodically to determine if the grass is staying in place. Any mowing of the channel should not damage the grass.

Riprap-lined channels

279. Check riprap-lined channels periodically to ensure that scour does not occur beneath the riprap layer. The channel should also be checked to determine if any stones have been dislodged by the flow.

Concrete-lined channels

280. Check concrete-lined channels periodically to ensure that there is no undermining of the channel. Pay particular attention to the outlet channel. If scour is occurring at the outlet, appropriate energy dissipation measures must be taken.

Sediment deposition

281. If the channel is below a high sediment-producing area, sediment should be trapped before it enters the channel. If sediment is deposited in grass-lined channels, it should be removed promptly to prevent damage to the grass. Sediment deposited in riprap- and concrete-lined channels should be removed when it reduces the capacity of the channel.

Slope grade conversions

282. A summary table of conversions of slope grade in terms of degrees, percent, and gradient is given in Table D-19 for quick reference.

Table D-19

Slope Grade Conversions

Convert from Degrees to Percent			Convert from Percent to Degrees		
Grade deg	Grade percent	Gradient	Grade deg	Grade percent	Gradient
1	1.8	1 in 56.0	0.6	1	1 in 100
2	3.5	1 in 28.6	1.2	2	1 in 50
3	5.2	1 in 19.2	1.7	3	1 in 33.3
4	7.0	1 in 14.3	2.2	4	1 in 25
5	8.8	1 in 11.3	2.9	5	1 in 20
6	10.5	1 in 9.5	3.4	6	1 in 16.7
7	12.3	1 in 8.1	4.0	7	1 in 14.3
8	14.0	1 in 7.1	4.6	8	1 in 12.5
9	15.0	1 in 6.3	5.1	9	1 in 11.1
10	17.6	1 in 5.7	5.7	10	1 in 10.0
11	19.4	1 in 5.2	6.3	11	1 in 9.1
12	21.3	1 in 4.7	6.8	12	1 in 8.3
13	23.1	1 in 4.3	7.4	13	1 in 7.7
14	24.9	1 in 4.0	8.0	14	1 in 7.1
15	26.8	1 in 3.7	8.5	15	1 in 6.7
20	36.4	1 in 2.7	9.1	16	1 in 6.3
25	46.6	1 in 2.1	9.6	17	1 in 5.9
30	57.7	1 in 1.7	10.2	18	1 in 5.6
35	70.0	1 in 1.4	10.7	19	1 in 5.3
40	83.9	1 in 1.2	11.3	20	1 in 5.0
			16.7	30	1 in 3.3
			21.8	40	1 in 2.5
			26.5	50	1 in 2.0
			31.0	60	1 in 1.7
			35.0	70	1 in 1.4
			36.9	75	1 in 1.3

APPENDIX E: PLANT MATERIALS TABLES

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Purpose

1. This appendix is provided to identify and describe those grass, herbaceous, and woody plant species that have been studied and found useful for stabilizing various problem soils. Problem soil materials encountered on Corps of Engineers project sites have been discussed in Sections II, IV, and V of the main body of this report.

Background

2. Studies of disturbed soils as found along highway rights-of-way in California (56)* and on large project sites in Mississippi (53) have demonstrated the absolute need to stabilize the site to be restored, with respect to controlling surface runoff waters. Thus, the tops of cut slopes must be stabilized before attempting to revegetate the disturbed soils.

3. Important kinds of information on the suitability of various plant materials for revegetating problem soil materials in the United States include:

- Ongoing studies of western and eastern surface mine lands (69, 75, 79, 85, 109).
- Revegetation of disturbed intermountain area sites in the southwestern United States (29, 68).
- Revegetation of disturbed soils in cold regions of New England and Alaska (66).
- Revegetation of the canal section of the Tenn-Tom Waterway (7).
- Evaluation of superior wildlife plants for disturbed lands (36, 47).
- Direct seeding of woody plants on highway construction sites (5, 43, 116, 117).
- Tolerance of grasses to acid, aluminum, and manganese toxic soils (17, 20, 21, 55, 108).
- Seed treatment of Mojave Desert shrubs to enhance establishment of woody plants (25, 26).
- Flood tolerance of riparian plants (77, 113).
- Propagation and culture of new drought-tolerant plants (9, 14).

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* See reference list at the end of this appendix (pp E-4 through E-12).

- After-the-fact establishment of persistent vegetation on highway cuts and fills (13, 27, 67, 82, 114).
- Evaluation of root cuttings for rapid cover of disturbed soils (28).
- Value of fresh-stripped topsoil for planting disturbed soils (34).
- Use of tubelings, condensation traps, and mature tree transplanting to revegetate disturbed soils in arid and semiarid climates (39).
- Testing and evaluating superior grass, legume, and tree varieties and cultivars for use on various problem soils of the United States (13, 29, 61, 62, 65, 83, 85, 109, 110, 112).

The above types of information were reviewed and the most useful information was compiled and tabulated in this appendix. Information on grass species is presented in Tables E-1 through E-6. Information on forbs and legumes is summarized in Tables E-7 and E-8. Tree and shrub information is summarized in Tables E-9 and E-10.

Grass Species

4. Information in Table E-1 summarizes grass species that can be grown on specific problem soil materials in specific regions of the country. Additional comments and appropriate literature cited for each grass species are summarized in Table E-2. From these tables, grass species can be selected for a specific problem soil material located at a specific project site in a specific region of the country. If more information is required, references are provided that can be reviewed.

Seeding Methods, Rates, and Dates

5. Information in Tables E-3 through E-6 on seeding rates and dates represents standardized recommendations made by the various states for revegetating critical areas (problem soils). Minimum rates of seeding are given for the broadcast plantings. In humid climates, the broadcast method is generally used. In situations where drilling is the seeding method, the seeding rate would be one half of that for the broadcast method. Drilling is preferred in arid and semiarid climates if the terrain allows the operation of machinery (38).

6. The difficulty of standardizing one mixture of grasses and legumes on a statewide basis dictates the use of many different combinations, rates, and planting dates. The mixtures and individual species listed herein are useful, but in the final analysis it will be necessary for the interdisciplinary survey team (Section III) to select the most appropriate species and mixtures for specific project sites.

Forbs and Legume Species

7. Information in Tables E-7 and E-8 is arranged in a similar manner to Tables E-1 and E-2 for grasses except that forbs and legume species are described. Use of these tables is exactly the same as described under grass species above.

Shrub and Tree Species

8. Information in Tables E-9 and E-10 is arranged in a similar manner to Tables E-1 and E-2 for grasses except that shrub and tree species are described. Use of these tables is exactly the same as described under grass species above.

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Table E-2 (Continued)

No.	Common Name	Scientific Name	Comments	References
75	Orchardgrass	*Dactylis glomerata*	Bunchgrass, shows good response to fertilizers. Matures early and grows up to 4 ft tall. Summer growth exceeds timothy or bromegrass.	3,6,11,14,30,32,63,69,75,79,80,82,83, 107
76	Lovegrass, weeping	*Eragrostis curvula*	Bunchgrass, strong root system and grows well on infertile soils. Short lived in northeastern United States. Has low palatability.	3,10,11,22,23,32,48,53,59,64,75,80,81, 82,83,85,90,96,97,101,102,104,106, 107,111,114
77	Lovegrass, purple	*Eragrostis spectabilis*	Bunchgrass; some plants produce short, slender rhizomes. Primarily adapted to medium- and coarse-textured soils. On heavily grazed areas, deer dig up the basal part of the stem during winter.	11,44
78	Centipedegrass	*Eremochloa ophiuroides*	Must start with a weed-free seedbed. Tolerates heat. Does not respond to fertilizers. Good for use on camping sites.	32,50,80,97,104
79	Fescue, creeping red	*Festuca rubra*	Sod forming and widely adapted to broad range of soil conditions, but is slow to establish. Grows best in cold weather. Good seed producer.	13,27,46,47,48,59,65,67,80,82,83,89,90, 91,96,101,106,107,114
80	Barley	*Hordeum vulgare*	Provides good winter cover provided that nitrogen-containing fertilizers are added to soil. Some barley strains show tolerance to salinity.	10,47,59,64,75,80,83,90,102
81	Ryegrass, annual	*Lolium multiflorum*	Excellent temporary cover. Seeds germinate quickly to provide quick cover. Plants will establish easily under dry soil conditions.	6,14,22,27,48,65,67,69,75,80,82,83,84, 85,96,101,106,107,114
82	Ryegrass, perennial	*Lolium perenne*	Bunchgrass. Longer lived than tall oatgrass and weeping lovegrass in the northeastern United States.	27,32,46,48,59,65,69,75,80,81,82,83,85, 91,96,101,106,107,114
83	Deertonguegrass	*Panicum clandestinum*, var. 'Tioga'	Very acid tolerant, drought resistant, and adapted to infertile soils. Volunteers in many areas. Must break seed dormancy by 30-day field stratification in late fall.	48,69,75,81,83,96,101,106,107,114
84	Panicum, spreading	*Panicum rhizomatum*	Best adapted to poorly drained acid to neutral (pH) deep sandy soils but grows well also on strongly acid, well-drained, deep sandy soils of the South.	44
85	Paspalum, Florida	*Paspalum floridanum*	Adapted to nearly level, acid to neutral somewhat poorly drained flatwood soils in the Coastal Plain and Florida. Robust, rhizomatous perennial.	44
86	Bahiagrass	*Paspalum notatum*	Must scarify seeds. Forms extensive root system; withstands heat and a wide range of soil conditions. Low maintenance costs. Semibunchgrass grows 1-3 ft tall.	3,22,23,32,49,50,53,59,64,75,78,80,82, 83,97,102,104
87	Timothy	*Phleum pratense*	Clumps grow more than 2 ft tall. Root system is fibrous and shallow. Usually sown in mixture with clover, alfalfa, or winter wheat. Best adapted to clay loam soils.	6,11,32,46,63,65,69,75,80,81,83,91,107, 111
88	Bluegrass, Canada	*Poa compressa*	Does well on droughty soils too infertile to support good stands of Kentucky bluegrass.	32,65,75,103,107,111
89	Bluegrass, Kentucky	*Poa pratensis*	Sod-forming and grows best on well-drained to somewhat poorly drained soils.	13,27,32,46,48,59,65,75,80,82,83,90,91, 96,101,106,107,111,114

(Continued)

(Sheet 6 of 7)

Table E-2 (Continued)

No.	Common Name	Scientific Name	Comments	References
61	Fescue, tall	*Festuca arundinacea* and cultivars	Adapted to acid and wet soils of sandstone and shale origins. Ideal for grassing of channels. Drought-resistant bunchgrass.	3,10,22,27,32,46,47,53,59,64,67,75,81, 82,83,89,90,95,96,97,101,104,106,107, 111,114
62	Switchgrass	*Panicum virgatum*	Rhizomatous root system. Adapted to infertile and saline soils and short lived in northeasten United States. Grows best when mixed with birdsfoot trefoil. Variety 'Blackwell' widely used.	3,11,32,44,46,48,51,58,75,78,79,80,81, 82,83,85,91,96,101,104,106,107,111, 114
63	Millet, pearl	*Pennisteum americanum*	Syn. with *P. ciliare*; will mature seed as far north as Maryland. Best growth requires addition of balanced fertilizer to soil. Thick clumps, grows to 6 ft or more. Four to ten pounds seed per acre give good results on fertilized soils.	10,76,85,90,104,107
64	Canarygrass, reed	*Phalaris arundinacea*	Ideal for wet areas. Excellent for use in drainage swales and gullies; grows well on saline-alkali soils. Not recommended for use in the State of Texas.	3,10,11,14,32,46,48,58,59,63,75,79,80, 81,82,83,90,91,96,101,106,107,111,114
65	Indiangrass	*Sorghastrum nutans*	Native sod forming; extends coverage by underground rhizomes. Matures at 3-7 ft tall. Seven excellent cultivars available. Key species used in rangeland mixtures. Adapted to deep moist clay soils.	11,30,32,44,58,69,80,82,83,91,104,107, 111
66	Redtop	*Agrostis alba*	Spreads by rhizomes and tolerates infertile soils. Adapted to wet sites and also tolerates drought.	3,10,11,27,32,46,48,59,63,64,69,75,80, 82,83,85,89,95,96,101,106,107,111,114
67	Bluestem pinehill	*Andropogon divergens*	Resembles big bluestem; bunchgrass. Most important on pine woodlands of coastal plain. Adapted to medium- and coarse-textured soils of the southern coastal plain and loess areas. Withstands moderate burning.	44
68	Bluestem, splitbeard	*Andropogon ternarius*	Native bunchgrass; grows best on ridges and knolls in coarse-textured soils. Can withstand periodic controlled burning.	44,104
69	Broomsedge	*Andropogon virginicus*	Native bunchgrass, volunteers readily on some disturbed soils. Coarse stems at maturity. Provides good cover for game birds and small game animals.	32,44,80,104,
70	Oatgrass, tall	*Arrhenatherum elatius*	Bunchgrass; especially suited to sandy and droughty soils in adapted regions. Short-lived perennial.	6,11,32,63,75,80,82,83,107
71	Bluestem, King Ranch	*Bothriochloa ischaemum* var. *songarica*	Related to yellow bluestem (*B. ischaemum*). In studies along Mississippi cuts and fills, King Ranch bluestem worked well in mixture with *Sericea lespedeza*.	51,76,78
72	Millet, browntop	*Brachiaria ramosa*	Introduced, rapid growing species. Produces quick cover and mature seeds in 60 days. Seed is choice food for upland game and nongame birds.	22,47,76,107
73	Brome, field	*Bromus arvensis*	Good winter cover plant material. Extensive fibrous root system. Makes rapid growth and easy to establish.	47,80,83,85,89
74	Rhodesgrass	*Chloris gayana*	Grows well on a strongly acid lignite soil. Recommended seeding rate in Mississippi is 25 lb/acre.	51,78,80

(Continued)

(Sheet 5 of 7)

Table E-2 (Continued)

No.	Common Name	Scientific Name	Comments	References
47	Dropseed, mesa	*Sporobolus flexuosus*	Native bunchgrass well adapted to sandy soils. Short-lived species but reseeds rapidly in areas with less than 8 in. of mean annual precipitation.	12,32,47,79
48	Dropseed, giant	*Sporobolus giganteus*	Native bunchgrass. Adapted best to deep sands and sandy soils. Can grow upward rapidly in sand dunes. Major grass in areas with 7-12 in. precipitation. Seeds available at times.	12,32,47,79,80
49	Needle-and-thread	*Stipa comata*	Native bunchgrass. Excellent for upland dune stabilization in areas with less than 10 in. annual precipitation.	11,32,44,79,80,82
50	Cottontop, Arizona	*Trichachne californica*	Native bunchgrass; responds rapidly to summer rains of arid West. Well adapted on dry mesas and rocky hills at 1000-6000 ft elevation. Seeds not yet easily available.	12,44,80
51	Trichloris, twoflower	*Trichloris crinita*	Native bunchgrass, extremely drought tolerant. Adapted to dry rocky slopes and sandy soils of arid West. Seeds are not commercially available.	44
52	Wheatgrass, western	*Agropyron smithii*	Native, sod-forming grass; spreads rapidly once established. Best for saline soils and tolerant to weakly alkaline soils. Cultivars are available. Tolerates periodic flooding.	1,11,14,30,32,33,51,65,78,79,80,82,83, 107,111
53	Bluestem, little	*Andropogon scoparius*	Native bunchgrass; major species of the central Great Plains and from Canada to south Texas. Better adapted to drier sites than big bluestem. The cultivar 'Pastura' is well adapted to extremes in temperature and precipitation.	11,32,48,50,58,69,75,79,80,82,83,91,96, 101,104,106,107,111,114
54	Oats, common	*Avena sativa*	Requires better soil drainage than ryegrass and will not persist at as low temperature as ryegrass or wheat. Provides supplemental feed for winter deer and rabbit. Requires nitrogen fertilizer for optimal growth.	10,47,48,59,63,69,75,80,82,83,90,104, 106,107,114
55	Grama, blue	*Bouteloua gracilis*	Native bunchgrass and well adapted to clayey upland soils. Tolerates heat and cold well. The cultivar 'Lovington' has outstanding seedling vigor. Forms sod by creeping growth habit. Poor seed availability.	11,12,30,32,47,51,58,78,79,80,82,83,111
56	Brome, smooth	*Bromus inermis*	Extensive fibrous root system. Easy to establish and provides quick cover.	11,14,30,32,47,63,65,75,79,80,82,83,91, 107
57	Windmillgrass	*Chloris verticillata*	Bunchgrass; grows on acid to neutral medium and coarse-textured soils. Growth starts in spring. Becomes dormant in fall.	11,44
58	Bermudagrass, common and cultivars	*Cynodon dactylon*	Tolerates drought, heat, and soil salinity. Propagated by runners or crowns. Addition of rock phosphate to soil greatly improves stand establishment and longevity; otherwise stands decline after fourth year.	3,10,22,32,59,64,69,78,80,82,83,90,97, 102,107
59	Lovegrass, plains	*Eragrostis intermedia*	Bunchgrass, grows well on dry upland sandy soils of arid west. Seeds are eaten by upland game birds.	44,79,80,82
60	Plumegrass, bent-awn	*Erianthus contortus*	Native bunchgrass; requires high soil fertility level. Grows throughout forested areas of the southern United States. Reproduces from seed. Grows in bunches 8-10 in. in diameter.	44,104

(Continued)

Table E-2 (Continued)

No.	Common Name	Scientific Name	Comments	References
32	Fescue, hard	*Festuca ovina duriuscula*	Introduced bunchgrass. Adapted to areas receiving 14+ in. of annual precipitation. Useful for soil stabilization and improvement. (Scientific name in Column 3 is synonymous with *F. longifolia*.)	14,47,65,79,80,82,111
33	Mesquite, curly	*Hilaria belangerii*	Sod forming via underground stolons. Grows on gravelly to rocky soils. Drought resistant. Cultivars not available.	44,80
34	Tobosa	*Hilaria mutica*	Introduced sod-forming grass. Does well on soils subject to flooding at elevations of 2000-6000 ft. No cultivars available.	44,80
35	Galleta, big	*Hilaria rigida*	Very drought tolerant. Slightly spreading, coarse grass. Good for certain saline sites.	79,80
36	Sprangletop, green	*Leptochloa dubia*	Native bunchgrass, adapted to rocky hills and canyons. The cultivar 'Marfa' was released for use in west Texas. Short-lived perennial.	12,44,51,78,111
37	Wimmera or Swiss ryegrass	*Lolium rigidum*	Rapid-growing bunchgrass. Best used in company with barley for temporary cover in arid climates. Tolerates saline soils; lives about 3 years.	14,79
38	Ricegrass, Indian	*Oryzopsis hymenoides*	Densely tufted form and one of the best drought-enduring native grasses. Grows on rocky and dry sandy soils.	11,12,27,65,79,80,82,111
39	Smilograss	*Oryzopsis miliacea*	Performs better on sandy soils than adapted strains of Hardinggrass in central and southern California. Cool season bunchgrass.	11,14,79,80
40	Kleingrass	*Panicum coloratum*	Good for certain saline sites. The cultivar '*Selection* 75' has been released.	12,79,80
41	Hardinggrass	*Phalaris tuberosa stenoptera*	Introduced sod former; best suited to clayey and clay soils in the winter rainfall area. The cultivar 'Wintergreen' showed good drought tolerance in west Texas.	32,79,80
42	Bluegrass, big	*Poa ampla*	Native bunchgrass. Favorite nesting site for pheasant. Successfully seeded in areas with 12 in. precipitation annually. Adapted best to soils with sandy to silt loam textures. Extensive root system and adapted to adverse sites.	11,14,30,32,65,79,80,82,111
43	Blowoutgrass	*Redfeldia fluxuosa*	Adapted to deep sandy soils that are prone to wind erosion. Not adapted to calcareous soil materials.	11,44,80
44	Sacaton, alkali	*Sporobolus airoides*	Native bunchgrass, tolerates saline-alkaline soils. Temporary irrigation required to establish a stand. Drought tolerant once established. Seed obtained from native stands. Provides excellent ground cover. Endures flooding on lowlands.	1,6,11,12,32,44,79,80,84,111
45	Dropseed, spike	*Sporobolus contractus*	Native bunchgrass that establishes rapidly on infertile soils. Grows on dry bluffs and sandy soils of arid West. Prolific seed producer and reseeds readily following drought.	11,32,47,79,80
46	Dropseed, sand	*Sporobolus cryptandrus*	Native bunchgrass well adapted to sandy soils and noted for increasing stands on disturbed lands. Prolific seed producer.	11,12,32,44,47,78,79,80,82

(Continued)

Table E-2 (Continued)

No.	Common Name	Scientific Name	Comments	References
15	Grama, red	*Bouteloua trifida*	Grows to 5-10 in. tall; has shallow root system and becomes semidormant in southern summers. Adapted to shallow, gravelly, stony soils (droughty) and invades better soils that are overgrazed. Seeds mature in 6 weeks.	44,47
16	Brome, California	*Bromus carinatus*, var. 'Cucamonga'	Native bunchgrass. Best adapted on coarse-textured soils with pH 5.5-8.0. Rapid developing, early maturing, self-seeding annual. Quick cover on disturbed areas.	47,79,80
17	Brome, blando	*Bromus mollis*	Introduced bunchgrass; used on sites unsuited for perennial grasses and for reseeding brush burns. Winter annual.	11,79,80
18	Bromegrass, red	*Bromus rubens*	Introduced annual bunchgrass; good soil stabilizer and erosion control species. Cultivars not available.	14,47,79,80
19	Buffalograss	*Buchloe dactyloides*	Sod-forming and spreads by stolons underground. Good for certain saline sites. Cultivars 'Texoka' and 'Sharps Improved' are best.	11,12,32,51,55,78,79,80,82,83,107
20	Sandreed, prairie	*Calamovilia longifolia*	Sod-forming grass; drought-tolerant species. Best for sandy soils. Poor seed availability.	11,32,79,80,82,83,111
21	Windmillgrass, hooded	*Chloris cucullata*	Native bunchgrass; produces several seed crops in one growing season. Not adapted to calcareous or dry soils.	44
22	Saltgrass, inland and coastal	*Distichlis stricta*	Native grass; seed difficult to find. Provides outstanding control of wind erosion on saline and alkaline soils. Tolerates periodic flooding.	3,11,32,44,47,79,80,82
23	Wildrye, basin	*Elymus cinereus*	Native bunchgrass, tall, coarse, and long-lived species. Tolerant to saline-alkali soils. Provides excellent cover for upland game birds.	11,30,32,79,80,82,111
24	Wildrye, mammoth	*Elymus giganteus*, var. 'Volga'	Sod-forming grass. Well adapted to saline soils and sand dune areas of the arid west. Propagated vegetatively.	32,65,79,80,92
25	Wildrye blue	*Elymus glaucus*	Native bunchgrass; highly drought resistant. Grows from sea level on Pacific Coast up to 10,000 ft elevation in Colorado.	11, 32, 79, 80, 82
26	Wildrye, Russian	*Elymus junceus*	Bunchgrass; well adapted to saline soils. Seed is commercially available.	6,11,32,79,80,82,111
27	Wildrye, beardless	*Elymus triticoides*	One of the most tolerant grasses to saline-alkali soils. Seed dormancy produces poor stand density in new seedlings.	11, 32, 79, 80, 82
28	Lovegrass, Boer	*Eragrostis chloromelas*	Bunchgrass; good for certain saline sites. Very drought tolerant. The cultivar 'A-84' has been released.	12,32,79,80,82
29	Lovegrass, Lehmann	*Eragrostis lehmanniana*	Introduced bunchgrass; less cold tolerant than weeping or Boer lovegrasses. Has more efficient water use than any other known forage species.	3,10,12,32,48,51,77,79,80,82,90,106, 111,114
30	Lovegrass, sand	*Eragrostis trichodes*	Bunchgrass. Well adapted and grows well on sands. Usually seeded in mixtures with other warm season grasses like bluestems and gramas in the West.	11,32,44,80,81,83,107
31	Fescue, Arizona	*Festuca arizonica*, var. 'Redondo'	Native bunchgrass; adapted to dry, shallow clay soils and sandy to gravelly soils. Extensively fibrous root systems makes for drought resistance and excellent soil stabilization.	11,30,47,82,111

(Continued)

(Sheet 2 of 7)

Table E-2

Additional Comments and References on Grasses Recommended for Establishing Persistent Cover on Problem Soil Materials

No.*	Common Name	Scientific Name	Comments	References**
1	Wheatgrass, crested	*Agropyron cristatum*	Introduced bunchgrass; drought resistant and long lived. Easy to establish and start growth early in spring. Seed is available in quantity.	14,30,32,33,58,65,79,80,82,111
2	Wheatgrass, crested 'Fairway'	*Agropyron cristatum*, var. 'Fairway'	Introduced bunchgrass. The sod-forming cultivar is best for use on dry soils. Long lived and drought resistant. Intolerant of prolonged flooding.	11,79,80,82
3	Wheatgrass, thickspike	*Agropyron dasystachyum*	Native sod-forming grass. Very good drought tolerance. Easier to establish than western wheatgrass (*A. smithii*).	11,30,32,33,65,79,80,82,111
4	Wheatgrass, standard crested	*Agrapyron desertorum*	Introduced bunchgrass. New seedlings grow slowly. Very drought tolerant and well adapted to certain saline-alkali soils of the arid west. Does not tolerate prolonged flooding.	3,11,30,33,65,79,80,82,111
5	Wheatgrass, tall	*Agropyron elongatum*	Bunchgrass, easily established on saline and alkaline soils. Several cultivars have wide adaptation and seeds available in quantity. Provides excellent cover for upland game birds.	30,32,65,79,80,82,83,111
6	Wheatgrass, streambank	*Agropyron riparium*	Native, sod-forming grass. Spreads rapidly once established. Adapted to saline and alkaline soils.	14,32,65,79,80,82,111
7	Wheatgrass, siberian	*Agropyron sibiricum*	Introduced bunchgrass. Very drought tolerant and well adapted to certain saline-alkali soils. New seedlings grow slowly. Intolerant of prolonged flooding.	30,32,65,79,80,82
8	Wheatgrass, slender	*Agropyron trachycaulum*	Bunchgrass. Best for saline-alkali sites; short lived but grows rapidly in mixtures.	6,30,32,33,65,79,80,82
9	Wheatgrass, pubescent	*Agropyron trichophorum*	Introduced, sod-forming, with good drought tolerance. More tolerant to alkaline soils than *Agropyron intermedium*.	11,14,30,32,33,65,79,80,82,111
10	Foxtail, meadow	*Alopecurus arundinaceus*, var. 'Garrison'	Introduced, sod-forming grass. Best on wet sites. Has strongly spreading root system. Well adapted to high altitudes in wetland pastures. Seed is available.	6,11,30,32,79,80,82,91
11	Bluestem, big	*Andropogon gerardii*	Native bunchgrass; adapted to sandy and silty clay soils; usually seeded in mixture with other species. Good cultivars are 'Kaw,' 'Pawnee,' and 'Champ.'	11,32,69,75,79,80,82,83,91,104,107,111
12	Bluestem, sand	*Andropogon hallii*	Sod-forming, grows well on deep sandy soils. Good species for soil stabilization in arid west.	11,12,32,78,79,80,82,91,111
13	Grama, sideoats	*Bouteloua curtipendula*	Native bunchgrass, adapted to calcareous soils. Usually seeded in mixtures with bluestems. Among nine cultivars, 'Vaughn' is drought tolerant with excellent seedling vigor.	11,12,30,32,47,51,58,78,79,80,82,83,91, 107,111
14	Grama, black	*Bouteloua eripoda*	Excellent for stabilizing soils and drought resistance. Tolerates calcareous soils. Seeds are available.	11,12,47,79,80,82

(Continued)

* Numbers in column one of Table E-2 refer to the same species listed in column one of Table E-1.
** Numbers in column five refer to References at the end of this appendix. Additional references to mixtures of grass species for humid climates are cited in Tables E-3 through E-6.

Table E-1 (Concluded)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
84	Panicum, spreading	*Panicum rhizomatum*		X						X			X	4.5		Y,Z,ZA,ZB	
85	Paspalum, Florida	*Paspalum floridanum*			X					X			X			Y,Z,ZA except Gulf Coast marshes	
86	Bahiagrass	*Paspalum notatum*	X	X					X	X			X	4.5		Q,Y,Z,ZA	
87	Timothy	*Phleum pratense*	X		X						X		X	4.5		O,P,R,S,T,U,V,W,X,Y	
88	Bluegrass, Canada	*Poa compressa*	X	X	X								X	4.5		O,R,S,T,U,W,X	
89	Bluegrass, Kentucky	*Poa pratensis*			X						X		X	5.5		O,P,R,S,T,U,V,W,X	
90	Rye, and cultivars	*Secale cereale*	X		X				X		X	X		5.5		O,P,Q,R,S,T,U,V,W, X,Y,Z	
91	Millet, foxtail	*Setaria italica*	X							X		X		5.5		O,P,Q,R,S,V,Y	
92	Johnsongrass	*Sorghum halapense*		X						X			X	6.0		Y,Z,ZA	
93	Sorghum X Sudan hybrids	*Sorghum* spp.	X	X						X		X		4.5		O,P,Q,R,S,T,U,V,W,X, Y,Z,ZA, & N. Pacific coast	
94	Sudangrass	*Sorghum sudanense*	X	X					X	X		X		5.5		O,P,Q,R,S,T,U,V,W,X, Y,Z,ZA, & N. Pacific coast	
95	Wheat and cultivars	*Triticum aestivum*	X								X	X		4.5		O,P,Q,R,S,T,U,V,W, X,Y	
96	Zoysiagrass	*Zoysia japonica*	X	X	X					X			X	5.0		P,Q,S,V,X,Y,Z, & N. Pacific coast	
97	Zoysiagrass, Meyers	*Zoysia japonica* var. *"Meyers"*	X	X						X			X	5.0		Q,V,Y,Z,ZA, & N. Pacific coast	
98	Zoysiagrass, Emerald	*Zoysia japonica X Zoysia tenuifolia*	X	X						X			X	5.0		Q,V,Y,Z,ZA, & N. Pacific coast	

(Sheet 6 of 6)

Table E-1 (Continued)

No.	Name: Commo.	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
68	Bluestem, splitbeard	*Andropogon ternarius*		X						X			X	4.5		P,Q,V,X,Y,Z	
69	Broomsedge	*Andropogon virginicus*			X					X			X	5.0		Y,Z,ZA	
70	Oatgrass, tall	*Arrhenatherum elatius*		X					X		X		X	5.0		O,P,R,S,T,U,V,W,X, & N. Pacific coast	
71	Bluestem, King Ranch	*Bothriochloa ischaemum* var. *songarica*		X			X			X			X			Q,Z	
72	Millet, browntop	*Brachiaria ramosa*			X					X		X		5.0		Region ZA mostly	
73	Brome, field	*Bromus arvensis*		X					X		X		X	6.0		O,P,R,S,T,U,V,W,X,Y	
74	Rhodesgrass	*Chloris gayana*	X			X				X			X	4.0		Y,Z,ZA	
75	Orchardgrass	*Dactylis glomerata*		X							X		X	5.0		O,P,R,S,T,U,V,W,X,Y	
76	Lovegrass, weeping	*Eragrostis curvula*	X	X					X	X			X	4.5		P,Q,V,X,Y,Z	
77	Lovegrass, purple	*Eragrostis spectabilis*		X						X			X	4.5		O,P,Q,R,S,T,U,V,W, X,Y,Z	
78	Centipedegrass	*Eremochloa ophiuroides*		X						X			X	4.5		Q,Y,Z,ZA,ZB	
79	Fescue, creeping red and cultivars	*Festuca rubra*		X	X						X		X	5.0		O,P,R,S,T,U,V,W,X,Y	
80	Barley	*Hordeum vulgare*	X			X					X	X		5.5		O,P,Q,R,S,T,U,V, W,X,Y,Z	F,N
81	Ryegrass, annual	*Lolium multiflorum*	X	X	X				X		X	X		5.5		O,P,Q,R,S,T,U,V,W,X, Y,Z, & N. Pacific coast	
82	Ryegrass, perennial	*Lolium perenne*	X	X	X				X		X		X	5.5		O,P,R,S,T,U,V,W,X,Y	
83	Deertonguegrass	*Panicum clandestinum*, var. "*Tioga*"	X	X					X	X			X	3.8		-S,U,V,W,X,Y	

(Continued)

(Sheet 5 of 6)

Table E-1 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
51	Trichloris, twoflower	*Trichloris crinita*					X			X			X		8-16		C,K,N
52	Wheatgrass, western	*Agropyron smithii*		X		X	X	X	X		X		X	4.5	14-20+	O,P,S,U,V,X	A,B,D,E,F,G,H, I,J,K,L
53	Bluestem, little	*Andropogon scoparius*		X			X		X	X			X	6.0	16-20+	O,P,Q,R,S,T,U,V,W, X,Y,Z	A,B,C,E,F,K
54	Oats, common	*Avena sativa*	X								X	X		5.5		O,P,Q,R,S,T,U,V,W,X, Y,Z	A,B,C,D,E,F,G, H,I,J,K,L,M
55	Grama, blue	*Bouteloua gracilis*		X					X	X			X	6.0	9-18	Q,R,T,U,W,X	A,B,E,F,J,K
56	Brome, smooth	*Bromus inermis*	X	X					X		X		X	5.5	17-20+	O,P,R,S,T,U,V,W,X, Y,Z	A,B,D,E,G,H, I,J,K
57	Windmillgrass, tumble	*Chloris verticillata*	X	X						X			X	5.0		P,Q,S,V,X,Y	B,E,F
58	Bermudagrass, common and cultivars	*Cynodon dactylon*	X	X		X		X		X			X	4.5	16-25+	Q,X,Y,Z,ZA	A,B,C,K,M,N
59	Lovegrass, plains	*Eragrostis intermedia*		X			X			X			X	5.0	14-20+	Q,Z	B,C,F,K
60	Plumegrass, bent-awn	*Erianthus contortus*			X					X			X			Q,Y,Z	
61	Fescue, tall	*Festuca arundinacea* and *cultivars*	X	X	X	X		X	X		X		X	5.0	18-20+	O,P,R,S,T,U,V,W,X,Y, Z, & N. Pacific coast	A,B,G,H,I,J,L, M,N
62	Switchgrass	*Panicum virgatum*	X		X	X		X	X	X			X	5.0	18-20+	O,P,Q,R,S,T,V,X,Y	A,B,C,K
63	Millet, pearl	*Pennisetum americanum*															
64	Canarygrass, reed	*Phalaris arundinacea*	X		X	X		X			X		X	5.0	18-20+	O,P,R,S,T,U,V,W,X, & N. Pacific coast	A,B,E,F,G,H,I, J,L,M
65	Indiangrass	*Sorghastrum nutans*		X	X			X		X			X	5.5	18-29+	P,Q,S,V,X,Y	A,B,C,F,K
66	Redtop	*Agrostis alba*	X	X	X				X		X		X	4.0		O,P,R,S,T,U,V,W,X,Y	
67	Bluestem pinehill	*Andropogon divergens*		X						X			X	4.5		Q,V,Z	

(Continued)

(Sheet 4 of 6)

Table E-1 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
33	Mesquite, curly	*Hilaria belangerii*					X			X			X		14-20+		B,C,F,K,N
34	Tobosa	*Hilaria mutica*						X		X			X		12-18		B,C,F,K,N
35	Galleta, big	*Hilaria rigida*				X				X			X		9-14		F,N
36	Sprangletop, green	*Leptochloa dubia*					X			X			X		12-20+		B,C,K
37	Wiwerma (or Swiss ryegrass)	*Lolium rigidum*				X			X		X	X			10-20+		M-
38	Ricegrass, Indian	*Oryzopsis hymenoides*					X				X		X		8-16		M-
39	Smilograss	*Oryzopsis miliacea*					X				X		X		16-20+		M-
40	Kleingrass	*Panicum coloratum*				X				X			X		18-20+		East, central, and west central Texas
41	Hardinggrass	*Phalaris tuberosa, Stenoptera*					X				X		X		16-20+		M. & central Texas
42	Bluegrass, big	*Poa ampla*					X				X		X		12-20+		D,E,G,H,I,L
43	Blowoutgrass	*Redfeldia flexuosa*					X		X	X			X		8-16		A,B,F
44	Sacaton, alkali	*Sporobolus airoides*				X	X	X			X		X		10-20+		A,B,C,D,E,F,G, H,I,J,K,-N
45	Dropseed, spike	*Sporobolus contractus*					X			X			X		10-18		B,F,I,J,K,N
46	Dropseed, sand	*Sporobolus cryptandrus*					X		X	X			X		10-18		A,B,C,E,F,G,H, I,K,N
47	Dropseed, mesa	*Sporobolus flexuosus*					X		X	X			X		8-12		C,I,K
48	Dropseed, giant	*Sporobolus giganteus*					X		X	X			X		8-12		B,C,F,I,K
49	Needle-and-thread	*Stipa comata*					X				X		X		10-16		A,B,D,E,F,G,H, I,J,K
50	Cottontop, Arizona	*Trichachne californica*					X			X			X		12-20+		B,C,F,K,N

(Continued)

(Sheet 3 of 6)

Table E-1 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
14	Grama, black	*Bouteloua eriopoda*					X				X		X		9-18		B,C,F,I,K
15	Grama, red	*Bouteloua trifida*					X			X			X		12-20+		C,F,K
16	Brome, California	*Bromus carinatus*, var. "Cucamonga"					X				X	X		5.5	10-20+		M, & N. Pacific coast
17	Brome, blando	*Bromus mollis*					X				X	X			12-20+		M
18	Bromegrass, red	*Bromus rubens*					X				X	X			14-20+		G,H,I,L,M,N
19	Buffalograss	*Buchloe dactyloides*				X				X			X		12-20+		A,B,C,K
20	Sandreed, prairie	*Calamovfila longifolia*					X			X			X		10-20+		A,B,J
21	Windmillgrass, hooded	*Chloris cucullata*					X			X			X		10-18		A,B,C,K
22	Saltgrass (inland and coastal)	*Distichlis stricta*				X			X	X			X		14-20+		A,B,G,H,I,J, K,M,N
23	Wildrye, basin	*Elymus cinereus*				X		X	X		X		X		14-20+		A,D,E,G,H,I,J,L
24	Wildrye, mammoth	*Elymus giganteus*				X	X		X		X		X		10-16		A,E,G,H,I,J,K
25	Wildrye, blue	*Elymus glaucus*						X			X		X				A,D,E,F,G,H,J, & north L
26	Wildrye, Russian	*Elymus junceus*				X					X		X		13-20+		A,D,E,F,G,H,I,J
27	Wildrye, beardless	*Elymus triticoides*				X		X			X		X		16-20+		A,E,G,H,I,J,K, L,M
28	Lovegrass, Boer	*Eragrostis chloromelas*				X			X	X			X		12-19		G,K,N
29	Lovegrass, Lehmann	*Eragrostis lehmanniana*					X			X			X	7.5	10-18		B,C,K,M
30	Lovegrass, sand	*Eragrostis trichodes*					X		X	X			X		16-20+		A,B,C
31	Fescue, Arizona	*Festuca arizonica*, var. "Redondo"					X				X		X		16-20+		F,J
32	Fescue, hard	*Festuca ovina duriuscula*					X				X		X		13-20+		A,D,E,G,H,I,L

(Continued)

(Sheet 2 of 6)

Table E-1

Characteristics and Suitability of Grasses Recommended for Establishing Ground Cover

No.*	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Perennial	Lower pH Tolerance**	Annual Precipitation Tolerance Range, in.†	Recommended Plant Growth Regions††: Humid	Recommended Plant Growth Regions††: Arid and Semiarid
1	Wheatgrass, crested	*Agropyron cristatum*					X				X		X		10-17		A,D,E,G,H,I,J
2	Wheatgrass, "Fairway" crested	*Agropyron cristatum*, var. "Fairway"					X				X		X		10-17		A,D,E,G,H,I,J
3	Wheatgrass, thickspike	*Agropyron dasystachyum*					X	X			X		X		10-17		A,D,G,H,I,J
4	Wheatgrass, standard crested	*Agropyron desertorum*				X	X		X		X		X		10-17		A,D,E,G,H,I,J
5	Wheatgrass, tall	*Agropyron elongatum*				X		X	X		X	X			14-20+		A,B,D,E,F,G,H, I,J,K,L,M,N
6	Wheatgrass, streambank	*Agropyron riparium*				X					X	X			11-19		A,D,G,H,I,J,L
7	Wheatgrass, Siberian	*Agropyron sibiricum*					X		X		X		X		10-16		A,D,E,G,H,I,J
8	Wheatgrass, slender	*Agropyron trachycaulum*				X					X		X		15-20+		A,B,D,E,G,H, J,L
9	Wheatgrass, pubescent	*Agropyron trichophorum*					X		X		X		X		12-18		A,B,D,E,F,G,H, J,L,M
10	Foxtail, meadow	*Alopecurus pratensis* var. "Garrison"						X			X		X	6.0	20+		D,E,H
11	Bluestem, big	*Andropogon gerardii*						X		X			X		16-20+		A,B,C,E,F
2	Bluestem, sand	*Andropogon hallii*					X			X			X		14-20+		A,B,C,E,K
3	Grama, sideoats	*Bouteloua curtipendula*					X			X			X	7.5	12-20+		A,B,C,E,F,K

(Continued)

* Numbers in column one of Table E-1 refer to the same species listed in column one of Table E-2.
** pH values listed refer to the lowest pH value at which the species will grow sufficiently to provide an acceptable ground cover.
† Range in precipitation applies only to arid and semiarid regions.
†† Letters refer to areas shown in Figures V-1 and V-2 of main text.

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Table E-2 (Concluded)

No.	Common Name	Scientific Name	Comments	References
90	Rye cultivars	*Secale cereale*	Temporary cover with strong root system. Survives well on coarse sandy soils.	3,10,14,22,46,48,64,67,75,80,82,83,85, 96,97,102,104,106,107,114
91	Millet, foxtail	*Setaria italica*	Requires the best achievable seed bed preparation. Cannot tolerate droughty soils. Provides temporary cover.	67,75,80,82,83,85,90,107
92	Johnsongrass	*Sorghum halapense*	Should not be planted close to cropped farmlands because it may spread as a pest. Requires abundant soil moisture. Plants contain small amounts of prussic acid but animal poisoning rarely occurs. Plants spread by vigorous root stocks. Perennial.	32,47,64,80,82,104
93	Sorghum X Sudan hybrids	*Sorghum* spp.	Temporary cover tolerates drought. Requires warm, dry soils. Tolerates pH 4.5 soils in eastern Kentucky. Annual species.	10,47,64,65,69,80,85,96,104,107
94	Sudangrass	*Sorghum sudanense*	Temporary cover, tolerates drought. Requires warm, dry soils.	3,10,22,32,46,47,48,65,75,80,83,90,97, 101,102,104,106,107,114
95	Wheat cultivars	*Triticum aestivum*	Requires well-drained soils and fertilized seedbed. Grows best in loamy soils. Cannot tolerate sandy and poorly drained soils.	22,47,64,69,75,80,83,85,96,97,102,104, 107
96	Zoysiagrass	*Zoysia japonica*	Introduced sod-forming grass. Propagated vegetatively (plugs). Seeds are available. Turns to golden brown color after heavy frost. Resists wear by foot traffic and more shade tolerant than common bermudagrass. Initial soil pH for establishment should be 6.0. Tolerates acid and alkaline soils.	80,104,115
97	Zoysiagrass, Meyers	*Zoysia japonica*, var. 'Meyers'	Grows best on heavy-textured soils. Complete fertilizer with 1-1-1 ratio (N-P-K) and an initial soil pH of 6.0 to 6.5 is required. Tolerates acid and alkaline soils. May be planted as plugs or seeds.	80,104,115
98	Zoysiagrass, Emerald	*Zoysia japonica x Zoysia tenuifolia*	Sod-forming grass; leaves narrower and finer than *Z. japonica*. May be planted as plugs or seeds. Grows best on heavy-textured soils well fertilized with 1-1-1 ratio (N-P-K) fertilizer. Tolerates acid and alkaline soils after establishment.	80,104,115

(Sheet 7 of 7)

Table E-3

Persistent and Temporary Plant Materials for Problem Soils of the Northern Great Lakes and St. Lawrence Region (Region W)
(Minimum seeding rate in lb/acre, broadcast)

	MAINE (46)										
	Excessively Drained/Dry Soils								Poorly Drained Soils		
A. Plant Materials For Developing Persistent Vegetative Cover on Problem Soils	Mixture No. 1	Mixture No. 2	Mixture No. 3	Mixture No. 5	Mixture No. 8	Mixture No. 15	Mixture No. 17	Mixture No. 18	Mixture No. 11	Mixture No. 12	Mixture No. 13
Tall fescue, Ky 31	25	15	~12	~7	64	10					
Red fescue	10	20	~5							3	
Redtop	3	3	3	3						3	
Ryegrass, perennial								8			
Switchgrass							10				
Reed canarygrass									10	8	8
Bentgrass, 'Seaside'											4
Kentucky bluegrass					16						
Ladino clover	1	1			1						
Crownvetch			15	15		15	15	15			

	Excessively Drained/Dry Soils					Poorly Drained Soils			
B. Plant Materials (Spring Seeded) For Temporary Cover and Green Manuring	Single Species No. 1	Single Species No. 2	Mixture No. 3	Mixture No. 4	Single Species No. 5	Single Species No. 1	Mixture No. 3	Mixture No. 4	Single Species No. 5
Japanese millet	25								25
Winter rye		120-180							
Medium red clover			10						
Mammoth red clover			10						
Timothy				5					
Redtop				2					
Alsike clover				4					
Sudangrass					30				

(Minimum seeding rates in lb/acre, broadcast)

A. Plant Materials For Developing Persistent Vegetative Cover on Problem Soils	Excessively Drained Dry and Deep Soils	Poorly Drained Soils	Disturbed and Eroded Areas	Waterways	Well-Drained Dry and Deep Soils	Poorly Drained Soils	Droughty Areas	Seepage Areas
Tall fescue, Ky 31	20		20	20	20* 20 20			
Redtop								
Creeping red fescue								
Reed canarygrass								
Perennial ryegrass								
Smooth bromegrass								
Annual ryegrass								
Deertongue grass	PLS	PLS						
Weeping lovegrass								
Kentucky bluegrass								
Switchgrass	PLS PLS PLS		PLS					
Little bluestem	PLS PLS		PLS					
Birdsfoot trefoil	5 10 6	8	8 8	8 10				
Korean lespedeza								
Flat pea	30 30		30		40*			
Crownvetch	15* 15* 15* 15*		15*		10*			
Ladino clover								
Red clover								
Sericea lespedeza								

*Inoculate

*Ky 31
*Tioga
*Inoculate

Erosion and Sediment Control

B. Plant Materials For Temporary Cover and Green Manuring	Mixture for Spring Seeding	Spring Seeding of SINGLE SPECIES ONLY	Late Spring and Summer Seeding of SINGLE SPECIES ONLY	Late Summer and Fall Seeding of SINGLE SPECIES ONLY	Well-Drained, Dry & Deep Soils: Spring & Fall Seeding of SINGLE SPECIES ONLY	Spring Seeding MIX	Poorly Drained Soils: Spring Seeding of SINGLE SPECIES ONLY	Summer Seeding of SINGLE SPECIES ONLY	Fall Seeding of SINGLE SPECIES ONLY	Droughty Areas & Slopes: Spring Seeding	Late Spring & Summer Seeding	Late Summer & Fall Seeding
Annual ryegrass	15	20	20	20	40							
Spring oats	64	96				96 96						
Winter rye				112	168							
Winter wheat				120								
Sudangrass			[illegible]									
German foxtail												
Weeping lovegrass												
Field bromegrass					40							
Korean lespedeza												
[illegible]												

(Continued)

[illegible]

Low Maintenance Sites

Mixture For Seeding Steep Slopes

SINGLE SPECIES ONLY For Seeding

Mixture For Seeding

Low Slopes and [illegible]

Spring Seeding of SINGLE SPECIES ONLY

Summer Seeding of SINGLE SPECIES ONLY

Fall and Early Winter Seeding of SINGLE SPECIES ONLY

Mixtures For Late Winter and Spring Seeding

SINGLE SPECIES For Late Summer Early Winter Seeding

[illegible]

(Continued)

[illegible]

Table E-6

Commonly Recommended Mixtures of Species for Seeding on Waterlogged Lands and on Waterlogged Land with Considerable Soil Salt in the Mountain Region (80)

	Waterlogged land in--							Waterlogged land-alkali salts*		
									Utah	
Species	Nevada	Utah	Idaho	Montana	Wyoming	Colorado	New Mexico	Montana	1	2
Smooth brome (*Bromus inermis*)		3				3				
Meadow fescue (*Festuca elatior*)		3	4			3	6-8			6
Tall fescue (*Festuca elatior* var. *arundinacea*)		[4]**	[4]**							[6]**
Perennial ryegrass (*Lolium perenne*)		3				4	4			
Redtop (*Agrostis alba*)	6		8	5-6	6					
Reed canarygrass (*Phalaris arundinacea*)		3		4-5		4	6-8			
Timothy (*Phleum pratense*)	6		6	5-8	6					
Western wheatgrass (*Agropyron smithii*)								10-14		6
Alsike clover (*Trifolium hybridum*)	4		2	2-3	3	2				
Yellow sweetclover (*Melilotus officinalis*)		3				2	2		8-10	
Strawberry clover (*Trifolium fragiferum*)		2				2	3-4	5-6		2-4
Total	16	17	20	16-22	15	20	15-26	15-20	8-10	2-16

Note: Measurements are in pounds per acre.
* More alkali than 2,000 ppm is damaging to ordinary pasture plants. When more than 3,500 to 4,000 ppm is present, salt-tolerant species as listed here must be used.
** Tall fescue is a high-yielding substitute for meadow fescue. It is rather low in palatability and is moderately salt-tolerant.

Table E-7

Characteristics and Suitability of Forbs and Legumes Recommended for Establishing Ground Cover

No.*	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Legume	Forbs	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Annual/Biennial	Longevity: Perennial/Biennial	Longevity: Perennial	Lower pH Tolerance or Range**	Annual Precipitation Tolerance Range, in.†	Recommended Plant Growth Regions††: Humid	Recommended Plant Growth Regions††: Arid and Semiarid
1	Deervetch, big	*Lotus uliginosus*						X	X			X				X		14-20+		A,G,H,I, North Pacific Coast and S. California
2	Medic, black	*Medicago lupulina*						X	X			X	X					14-20+		A,G,H,I
3	Alfalfa	*Medicago sativa*					X	X	X			X				X		17-20+		A,B,D,E,F,G,H,I,J,K, L,M,N
4	Hemp, Colorado River	*Sesbania exaltata*						X	X			X	X					18-35		E,F,G,H,M
5	Clover, strawberry	*Trifolium fragiferum*				X		X	X			X			X	X		18-20+		A,G,H,I
6	Clover, alsike	*Trifolium hybridum*						X	X			X				X		18-20+		A,G,H,I,F
7	Clover, white	*Trifolium repens*						X	X			X				X		18-20+		A,B,D,G,H,I
8	Clover, subterranean	*Trifolium subterranean*				X			X			X	X					16-20+		M
9	Vetch, Hungarian	*Vicia pannonica*						X	X			X	X					18-35		E,F,G,H, and N. Pacific Coast
10	Vetch, hairy	*Vicia villosa*				X	X		X			X	X					18-20+		A,B,E,G,H,I
11	Yarrow, Western	*Anchillea millefolium lanulosa*				X				X	X					X		12-18		D,E,G,H,I
12	Prickle Poppy	*Argemone intermedia*					X			X	X		X					>20		Nebraska Panhandle
13	Plains coreopsis	*Coreopsis tinctoria*						X		X		X	X					>20		Nebraska Panhandle
14		*Eriogonum bailiyii*					X			X	X		X					14-20+		Nevada
15		*Eriogonum nidularium*					X			X	X		X					14-20+		Nevada
16	Poppies, gold	*Eschscholtzia* spp.					X			X	X		X					10-14		K,M,N
17	Rattlesnake weed	*Euphorbia albomarginate*				X	X			X	X					X		14-20+		Utah, Nevada, and West Texas

(Continued)

* Numbers in column 1 of Table E-7 refer to the same species listed in column 1 of Table E-8.
** pH values listed refer to either the lowest pH value at which the species will grow sufficiently to produce an acceptable ground cover or the range in pH for normal growth.
† Range in precipitation applies only to arid and semiarid regions.
†† Letters refer to areas shown in Figures V-1 and V-2 of main text.

(Sheet 1 of 3)

Table E-7 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Legume	Forbs	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Annual/Biennial	Longevity: Perennial/Biennial	Longevity: Perennial	Lower pH Tolerance or Range	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
18	Sunflower, annual	*Helianthus annuus*					X			X	X		X					8-16		A,B,G,H,I,J
		'Jaegeri'						X		X		X	X					6-14+		E,F,I
19	Sunflower, stiff	*Helianthus laetiflorus*					X			X	X					X		16-20+		A,B
20	Morning glory, bush	*Ipomoea leptaphylla*					X			X	X					X		14-20+		A,B
21	Summer cypress, prostrate	*Kochia prostrata*				X				X	X					X		12-18		A,B,E,F,H,I,J,K,L
22	Grayfeather lanceleaf	*Liatris lancifolia*						X		X		X				X		>20		Nebraska Panhandle
23	Primrose, evening	*Oenothera caespitosa* var. *'Marginata'*					X			X		X				X		15-20+		Nevada, Western Utah, and Eastern Washington
24	Penstemon, palmer	*Penstemon palmeri*						X		X		X				X		15-20+		F,I
25	Penstemon Rocky Mountain	*Penstemon strictus* var. *'Bandera'*						X		X		X				X		14-20+		B,E,F,L
26	Phlox, Douglas	*Phlox douglasii* Sub-specie *'Rigida'* (Per)				X	X			X	X					X		14-20+		Nevada
27	Clammyweed, large flower	*Polanisia trachysperma*					X			X	X		X					>20		Nebraska Panhandle
28	Milkvetch, cicer	*Astragalus cicer 'Lutana'*			X	X	X	X	X			X	X		X		5.5-7.0	18-35	W,X	A,B,E,G,H,I,J,K,L
29	Trefoil, birdsfoot	*Lotus corniculatus*	X	X	X			X	X			X				X	5.0-7.5	18-20+	O,P,R,S,T,U,W,X,Y,and N. Pacific Coast	A,B,D,E,F,G,H,I,K
30	Sweet clover, white	*Melilotus alba*		X			X	X	X			X		X	X		6.0-8.0	16-20+	O,P,Q,R,S,T,U,V,W, X,Y,Z	A,B,C,D,E,F,G,H,I,J, K,L,M
31	Vetch, crown	*Coronilla varia*	X	X					X			X				X	5.0-7.5		O,P,R,S,T,U,W,X,Y, and N. Pacific Coast	
32	Crotalaria, lance	*Crotalaria lanceolata*	X	X					X		X		X				4.5-6.0		V,X,Y,Z,ZA,ZB	
33	Flatpea 'Lathco'	*Lathyrus sylvestris* var. *'Lathco'*	X	X					X			X				X	4.5-7.0		O,P,Q,R,S,T,U,V,W, X,Y,Z	
34	Lespedeza, sericea	*Lespedeza cuneata*	X	X					X		X					X	4.5-7.0		P,Q,S,V,X,Y,Z	
35	Lespedeza, prostrate	*Lespedeza cuneata* *'Ky-520'*	X	X					X		X					X	4.5-7.0		P,Q,S,V,X,Y,Z	

(Continued)

Table E-7 (Concluded)

No.*	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline-Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Legume	Forbs	Season: Warm	Season: Cool	Longevity: Annual	Longevity: Annual/Biennial	Longevity: Perennial/Biennial	Longevity: Perennial	Lower pH Tolerance or Range	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
36	Lespedeza, Korean	*Lespedeza stipulacea*	X						X		X		X				4.5		S,V,X,Y,Z	
37	Lespedeza, common	*Lespedeza striata* var. *'Kobe'*	X	X					X		X		X				4.5-6.0		S,V,X,Y,Z,ZA, and ZB	
38	Sweetclover, yellow	*Melilotus officinalis*		X					X			X		X			6.0-6.0		O,P,Q,R,S,T,U,V,W, X,Y,Z	
39	Clover, crimson	*Trifolium incarnatum*		X					X			X		X			5.5-7.0		P,Q,V,Y,Z, and ZA	
40	Clover, ball	*Trifolium nigrescens*		X					X			X		X			5.0-7.0		V,Z, and ZA	
41	Clover, Persian	*Trifolium resupinatum*			X				X			X	X				5.5-7.0		Y,Z, and ZA	
42	Cowpea	*Vigna sinensis*		X	X				X		X		X				5.5-7.0		P,Q,V,Y,Z, and ZA	
43	Yarrow, common	*Achillea millefolium*		X						X		X				X	5.0-6.0		O,R,S,T,U,V,W,X,Y,Z	
44	Yarrow, wooly	*Achillea tometosa*		X						X		X				X	5.0-6.0		O,R,S,T,U,V,W,X,Y	
45	Coreopsis, dwarf eared	*Coreopsis auriculata*		X						X		X				X	5.0-7.0		X,Y,Z, and ZA	
46	Buckwheat	*Fagopyrum* spp.	X	X						X	X		X				4.5-7.0		O,P,Q,R,S,T,U,V,W,X,Y,Z	
47	Sunflower, swamp	*Helianthus angustifolius*	X	X	X					X	X		X				5.0-7.0		P,Q,S,V,X,Y,Z, and ZA	
48	Sunflower, annual	*Helianthus annuus*	X	X						X	X		X				5.0-7.0		O,P,Q,R,S,T,U,V,W,X,Y,Z	
49	Daylily	*Hemerocallis fulva* var. *'Europa'*			X					X		X				X	5.0-7.0		R,S,T,U,V,W,X,Y,Z	
50	Fleeceflower, Japanese	*Polygonum cuspidatum*	X	X						X		X				X	3.2-6.0		O,P,R,S,T,U,V,W,X	
51	Knotweed	*Polygonum muhlenbergii*			X					X		X				X	5.0-7.0		P,Q,R,S,T,U,V,W,X,Y,Z, and ZA	
52	Smartweed	*Polygonum pennsylvanicum*			X					X	X		X				5.0-7.0		P,Q,R,S,T,U,V,W,X,Y,Z, and ZA	
53	Germander chamedrys	*Teucrium chamaedrys*		X						X		X				X	5.0-7.0		P,Q,S,W,Z	

(Sheet 3 of 3)

Table E-8

Additional Comments and References on Forbs and Legumes Recommended for Establishing Ground Cover

No.*	Common Name	Scientific Name	Comments	References**
1	Deervetch, big	*Lotus uliginosus*	Introduced specie. Upright growth habit; grows 3-4 ft tall. Stems die down partially each season. Forage value medium to high. Grows throughout the West.	14,41
2	Medic, black	*Medicago lupulina*	Native specie. Reseeds readily and grows at higher elevations than other annual medics.	4,32,33,82
3	Alfalfa	*Medicago sativa*	Requires soil calcium. Will grow on moderately alkaline soils and has moderate salt tolerance. Deep rooted. Seed of many varieties available in quantity. Consult local agencies for recommended varieties for they vary widely in adaption to various soils. For poorly drained soils use varieties adapted to moist conditions. Most valuable of all legumes to wildlife--both for forage and seed.	2,6,18,27,32,33 40,41,69,73,74, 82,107,111
4	Hemp, Colorado River	*Sesbania exaltata*	Somewhat shrubby annual; grows 4-12 ft tall. An important food source for bobwhite quail. Used as food by mallard duck and Gambel quail.	
5	Clover, strawberry	*Trifolium fragiferum*	Introduced specie. Moderate salt tolerance. Grows on alkaline soils subject to flooding. Useful in reclaiming moist meadows rendered alkaline by seepage from irrigation ditches.	14,32,41,73,82,111
6	Clover, alsike	*Trifolium hybridum*	Introduced specie. Short lived. Low to moderate salt tolerance. Excellent for attracting honey bees.	2,4,6,32,41,69,73, 74,82,107,111
7	Clover, white	*Trifolium repens*	Introduced specie. Sod-forming. Best adapted to moderately fine- to medium-textured soils. Valuable food source for deer, game birds, song birds, and rodents. Excellent for attracting honey bees.	2,4,32,41,69,73,74, 82,107,111,113
8	Clover, subterranean	*Trifolium subterranean*	Prostrate growth habit. Does best on well-drained and fertile soils. Reseeds annually.	14,32
9	Vetch, Hungarian	*Vicia pannonica*	Introduced specie.	6,32,82
10	Vetch, hairy	*Vicia villosa*	Introduced specie. Sod-forming. More tolerant to alkaline soils than most legumes. Tolerates moderately alkaline soils. Use limited to areas with plentiful soil moisture or irrigation.	4,6,18,32,41,69,73, 82,107
11	Yarrow, Western	*Achillea millefolium lanulosa*	Can be direct seeded, but seedling transplants are preferred. Tolerates alkaline and acid soil conditions.	72,111,113
12	Prickle Poppy	*Argemone intermedia*	Grows on noncalcareous dry sands, sandy and clayey soils in association with evening primrose and cacti. Best for sand washes and tops of cut and fill slopes. Reseeds readily each season.	52
13	Plains coreopsis	*Coreopsis tinctoria*	Tolerant of saline soils. Does best on noncalcareous soils. Reseeds readily.	52
14		*Eriogonum bailiyii*	Native specie. Adapted to sandy and gravelly flats or banks. Rodents eat seed.	

(Continued)

* Numbers in column one of Table E-8 refer to the same species listed in column one of Table E-7.
** Numbers in column five refer to References at the end of this appendix.

(Sheet 1 of 4)

Table E-8 (Continued)

No.	Common Name	Scientific Name	Comments	References
15		*Eriogonum nidularium*	Pioneer specie adapted to dry soils. Grows best at elevations below 6000 ft. Erect growth habit.	
16	Poppies, gold	*Eschscholtzia* spp.	Best in dry warm climates. Grows on loose gravel or on sandy areas where competition with grasses is limited. Suspected of being poisonous to animal and man.	
17	Rattlesnake weed	*Euphorbia albomarginate*	Pioneer specie. Adapted to alkaline soils. Prostrate growth habit. Occurs at elevations up to 7500 ft.	33,73
18	Sunflower, annual	*Helianthus annuus* 'Jaegeri'	Adapted to a wide range in soil texture. Grows well on alkaline soil and adapted to wet, moderately alkaline sites. Tolerates moderate salinity. Easily grown from seed. Often considered a weed.	69
19	Sunflower, stiff	*Helianthus laetiflorus*	Has potential for use in wildlife plantings. Good potential for initial establishment and seed production.	[illegible]
20	Morning glory, bush	*Ipomoea leptaphylla*	Shrubby forb (2-5 ft). Grows well on upland sand dunes. Very drought tolerant. Tuberous rootstock stores moisture. Planting materials not currently available.	[illegible]
21	Summer cypress, prostrate	*Kochia prostrata*	Introduced shrub for saline-alkali soils. Long lived with extensive root system and exceptional drought tolerance.	
22	Grayfeather lanceleaf	*Liatris lancifolia*	Grows best on noncalcareous soils and wet swales in full sun or partial shade. Outstanding bright lavender flowers.	[illegible]
23	Primrose, evening	*Oenothera caespitosa* var. *'Marginata'*	Grows well on calcareous soils, steep banks, and sandy swales.	[illegible]
24	Penstemon, palmer	*Penstemon palmeri*	Native, short lived, and sod-forming. Adapted to roadside washes at 3500 to 6500 ft. Provides browse for game animals.	
25	Penstemon, Rocky Mountain	*Penstemon strictus* var. *'Bandera'*	Native, bunch-forming and long lived. Adapted to sandy soils at 6,000 to to 11,000 ft. Established from seed or sprigs. Seedlings are vigorous.	14,82,111
26	Phlox Douglas	*Phlox douglasii* subsp. *'Rigida'*	Pioneer specie. Adapted to rocky and gravelly soils. Compact growth, low growing from a woody base. Potential value in erosion control.	33
27	Clammyweed, large flower	*Polanisia trachysperma*	Agressive pioneer specie. Tolerates dry noncalcareous sandy washes and dry stream beds. Reseeds readily each season.	52
28	Milkvetch, cicer	*Astragalus cicer 'Lutana'*	Introduced specie. Sod-forming. Tolerates moderately alkaline soils. Use is limited to areas with plentiful soil moisture or irrigation. In humid regions, will tolerate both wet and dry conditions. Germination is slow and young seedlings may be crowded out by other species.	14,32,33,40,41,82 107,111,117

(Continued)

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Table E-8 (Continued)

No.	Common Name	Scientific Name	Comments	References
29	Trefoil, birdsfoot	*Lotus corniculatus*	Tolerates both wet and dry soil conditions. Very drought and heat tolerant. Roots penetrate deeply into sandy and infertile soils. Seed readily available. Inoculate at seeding. Most widely used varieties in the Northeastern United States are Mansfield and Viking. Viking variety grows well on acid sandy soils but should be mixed with tall fescue for best results. Viking is inferior to crown vetch and flat pea when seeded alone.	4,14,27,32,41,57,69, 73,74,82,107,113, 117
30	Sweetclover, white	*Melilotus alba*	Widely adapted to soils throughout the West except the Southwestern desert and California valleys. Grows to around 5 ft high. In humid regions, it is an excellent green manure source. Food for deer, quail, dove, and pheasant. An important invader of mined lands in Illinois.	27,32,69,73,82,107, 111
31	Vetch, crown	*Coronilla varia*	Excellent for dry areas but has limited shade tolerance. Requires a pH of 5.5 or higher for establishing maximum stand density but will tolerate a soil pH of 4.5 after establishment. Slow to establish but grows rapidly the second season. Growth is too vigorous to be planted with conifers during year that the trees are planted. Seed available.	2,4,14,18,23,27,32, 33,41,50,57,67,69, 74,82,108,111,117
32	Crotalaria, lance	*Crotalaria lanceolata*	Grows well on infertile, acid, sandy soils. Resistant to root knot nematodes. Three cultivars available. Seeds are poisonous.	32,41
33	Flatpea 'Lathco'	*Lathyrus sylvestris* var. *'Lathco'*	Drought tolerant. Deep rooted. Tolerates infertile soils but stand develops slowly if not fertilized. For best results at seeding, lime the surface soil to a pH of about 6.0. Climbing perennial that suppresses invading forbs and woody plants. Vigor due to rhizomatous root habit. Food and cover for grouse, dove, geese, and pheasant.	32,69,74,107,117
34	Lespedeza sericea	*Lespedeza cuneata*	Drought tolerant. Seed should be scarified. Bunchlike growth with woody stems - 2 to 3 ft tall. Desirable for seeding with mixtures of black locust and Virginia pine. Produces seed and cover for upland game.	3,4,27,32,49,50,53, 57,69,82,107,117
35	Lespedeza prostrate	*Lespedeza cuneata 'Ky-520'*	Drought tolerant. Consistently established dense stands on acid mine spoil in Appalachian valleys and plateaus. Plantings spread to outlying areas.	32,107
36	Lespedeza Korean	*Lespedeza stipulacea*	Reseeds annually to give increased stand density. Provides seed and cover for game birds.	4,32,57,69,107
37	Lespedeza common	*Lespedeza striata* var. *'Kobe'*	Pioneer specie in revegetation of disturbed areas. Thrives in sands but grows best on well-drained, fertile soils. Extensive root system. Reseeds annually for increased stand density. Provides seed and cover for upland game birds. Important food for bobwhite quail.	27,69,82,107
38	Sweetclover, yellow	*Melilotus officinalis*	Can be established more easily than *M. alba* in droughty soils. Grows to about 5 ft. Provides seeds for game birds.	2,6,14,27,32,40,41, 69,73,74,82,108,111
39	Clover, crimson	*Trifolium incarnatum*	Annual legume. Excellent green manure plant.	14,32,74,82,107
40	Clover, ball	*Trifolium nigrescens*	Does best on deep, sandy soils. Will tolerate considerable soil acidity. Supplemental food in winter for deer, turkey, and rabbits.	32

(Continued)

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Table E-16 (Continued)

No.	Common Name	Scientific Name	Comments	References
52	Pea, chaparral	*Pickeringia montana*	Legume. Uncovered roots will sprout. Crown sprouts after a fire. Browsed by California mule deer.	73
53	Antelope brush	*Purshia tridentata*	Fairly deep root system. Prefers full sun. Occurs in clays, sand, and other soils. Important browse plant for sheep and cattle.	56,111
54	Firethorn	*Pyracantha coccinea*	Produces abundant berries. Evergreen in southwestern United States. Grows about 6 ft tall. Difficult to transplant except when small. Shade intolerant.	31,73,110
55	Sumac, mahogany	*Rhus integrifolia*	Very drought resistant. Lower branches take root where they touch the ground. Vigorous lateral roots. Food for birds and mule deer.	14,73
56	Jojoba (Goat nut)	*Simondsia chinensis*	Seedlings are slow-growing. Important livestock browse. Eaten by mule deer, squirrels, and white-winged doves.	73
57	Acacia, catclaw	*Acacia greggii*	Legume. Excellent drought tolerance. Native thicket-forming small tree. Tolerates calcareous soils. Grows between 1000-4500 ft elevation. Seed can be obtained from commercial jobbers.	73
58	Acacia, catclaw	*Acacia tortuosa*	Shade intolerant. Legume. Prefers dry sites.	
59	Birch, water	*Betula occidentalis*	Wet-site tree. Used by sapsuckers and other birds, and beavers. Grows in bottoms.	73
60	Desert willow	*Chilopsis linearis*	Large shrub to small tree. Tolerates calcareous soils.	12,14,73,111
61	Desert willow	*Chilopsis linearis* var. 'Barranco'	New released variety recommended for soil stabilization below 5000 ft.	
62	Hawthorn fireberry	*Crataegus chrysocarpa*	Shows potential for use on mined lands in the Dakotas. Fruit very attractive to birds.	73,107
63	Hawthorn western, black	*Crataegus douglasii*	Grows on extremely dry or moist sites. Usually forms thickets and provides dense cover. Valuable plant for erosion control and wildlife.	33,73,107
64	Olive, Russian	*Elaeagnus*	Small tree. Very resistant to drought. Valuable food for birds and fox squirrels.	73
65	Olive, Russian	*Elaeagnus angustifolia*	Shade intolerant. Drought resistant, winter hardy, rapid growing, and tolerates alkaline and saline soils. Does well on a wide range of soil and moisture conditions. Widely used in windbreaks. King-red variety has wide adaption.	14,31,52,54,69,71,73,107,116
66	Ash, white	*Fraxinus americana* var. *microcarpa*	Shade intolerant. Rapid growing. Root system deep and fibrous.	52,54,69,71,107
67	Ash, velvet	*Fraxinus velutina*	Reported as most alkali and drought tolerant form. Shade intolerant. Prefers moist sites.	5,12,73
68	Ash, velvet (desert ash)	*Fraxinus velutina coriacea*	Tolerates wet sites or areas with standing water. Alkali tolerant. Grows below 5000 ft elevation.	
69	Honey locust	*Gleditsia triacanthos*		

(Continued)

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Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
36	Hackberry, spiny	*Celtis pallida*	Seed germination reported to be low. Grows on gravelly soils to heights of 3-10 ft Forms dense thickets. Good cover for game birds. Good honey plant but unattractive to livestock.	
37	Mountain mahogany, curl leaf	*Cercocarpus ledifolius*	Large shrub. Grows on gravelly soils. Outstanding browse for mule deer.	14,33,73,111
38	Quinine bush	*Cowania mexicana stansburiana*	Staple food of mule deer. Increased branching occurs under browsing.	73,111
39	Brittlebush, white	*Encelia farinosa*	Adapted to gravelly and dry slopes. Browsed by bighorn sheep and Gambel quail.	14,73
40	(None given)	*Ephedra fasiculata*	Prostrate growth habit. Slender stems. Good for mule deer and Arizona cottontail rabbits.	73
41	(None given)	*Ephedra funerea*	Evergreen spinose shrub. Extensive branching. Wildlife value.	73
42	Popotillo	*Ephedra trifurca*	Often spinescent. Good for birds and mountain sheep.	12,73
43	Yerba-santa, narrowleaf	*Eriodictyon angustifolium*	Prefers full sunlight. Grazed largely by goats.	73
44	Winterfat	*Eurotica lanata*	Deep and spreading root system. Rapid growing. Often occurs on calcareous desert valley bottoms. Abundant seed producer. Readily established from seed but seed available only from native stands. Important winter browse for deer and elk and provides good livestock forage. Not recommended for rapid stand development in Montana.	14,33,52,73,82
45	Bursage, triangle	*Franseria deltoides*	Grows on rocky slopes and canyons (6 in. high by 12 in. wide). Can be established by direct seeding. Limited amounts of seed and plants available.	82
46	Bursage, white	*Franseria dumosa*	Drought tolerant. Valuable in stabilizing problem soils. Seed supply limited. Used by wildlife.	14,73,82
47	Bladderpod	*Isomeris arborea*	Promising for stabilizing problem soils by direct seeding. Can be direct seeded in deserts. Drought resistant because of deep, fast-growing root system.	5,14
48	Junipers (shrub forms)	*Juniperus communis*	Thrives on almost any soil. Long lived but slow-growing. Rarely exceeds 3 to 4 ft tall.	14,41,54,73,82
49	Juniper, cherrystone	*Juniperus monosperma*	May be either a shrub or a small tree. Rapid growing for a juniper. Long lived. Does not tolerate shade. Prefers dry, sunny sites and occurs at elevations between 4000-7500 ft in the southwestern part of its range. May become a pest on south-western ranges. Fruit eaten by deer, Hopi chipmunk, and birds.	12,73
50	Creosote bush	*Larrea divaricata*	Poor for restoration of problem soils in desert southwest. Can be direct seeded. Cover for wildlife and food for desert lizard.	14,73
51	Oleander	*Nerium oleander*	Withstands drought and heat. Easily rooted from cuttings. Contact with leaves can produce dermatitis.	14,31

(Continued)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
17	Molly, green	*Kochia americana*	Grows well on alkali flats with puddled soils. Shows promise for soil stabilization. Grows about 2 ft tall. Browsed by sheep.	73
18	Seale broom	*Lepidospartum squamatum*	Prefers sandy wastes and gravelly plains. Occurs on sand dune areas of Mojave Desert. Very drought resistant.	
19	Mendora, rough	*Mendora scabra*	Good on dry, rocky, and sandy places. Browse specie.	73
20	Dalea, Fremont	*Parosela fremontii*	Small leguminous shrub. Prefers dry sunny sites.	
21	Dune broom	*Parryella filifolia*	Small much branched shrub (about 3 ft tall). Grows well on rolling, treeless, sandy plains. Good stabilizer for sandy soils. Easily established from seed obtained from native stands. Unpalatable to livestock.	
22	Fleabane	*Pluchea sericea*	Often forms pure, dense stands. Browsed by California mule deer.	73
23	Milkwort	*Polygala subspinosa*	Good on gravelly and dry sandy soils. Much branched and tufted under shrub.	73
24	Plum, wild	*Prunus americana*	Shade tolerant. Sprouts from roots to form dense colonies.	31,52,73,113
25	Peach, desert	*Prunus andersonii*	Extremely drought resistant. Well developed taproot. Spreads readily. Grows well on gravelly soils. Browsed by large animals.	14,73
26	Almond, desert	*Prunus fasiculata*	Good on gravelly and sandy soils. Forms dense thickets. Furnishes some browse for goats.	73
27	Sumac, lemonade	*Rhus trilobata*	Endures extreme drought. Tolerates shade.	14,52,73,111
28	Buffaloberry, silver	*Shepherdia argentea*	Tolerates shade. Difficult to transplant from the wild but commercial stock is available. Profuse fruit production. Excellent cover and food for wildlife. Used as windbreak and ornamental plant. Has great promise.	52,73,107,111,116
29	Snow berry	*Symphoricarpos albus*	Forms thickets. Grows on calcareous soils.	33,41,111
30	Grape, Long's	*Vitis Longii*	Drought and cold resistant. Deep and much branched root system. Sixty percent of the root cuttings root.	52
31	Fourwing salt-bush	*Atriplex canescens*	Very drought tolerant. Has a deep and extensive root system. Rapid growing. Tolerant of alkaline soils; grows on calcareous and saline soils with textures ranging from sands to clays. Prolific seed producer. Seed can be planted as soon as ripe. Different populations show a wide range of variability. Palatable and nutritious. Used by game birds and live stock.	14,33,40,73,82,111
32	Holly, desert	*Atriplex hymenelytra*	Small desert shrub. Prefers full sunlight. Apparently not browsed.	73
33	Quail bush	*Atriplex lentiformis*	Provides excellent cover for wildlife. Promising soil stabilizer of problem soils.	5,73
34	Salt bush, Nuttall	*Atriplex nuttallii*	Occurs on alkaline clay soils of Northern Great Plains. Provides excellent cover and soil stabilization.	14,33,73,111
35	Holly grape, Fremont	*Berberis freemontii*	Very tolerant to dry soils and low precipitation. Often forms dense clumps. Browsed by mule and black-tailed deer.	73

(Continued)

(Sheet 2 of 13)

Table E-10

Additional Comments and References on Shrubs and Trees Recommended for Establishing Ground Cover

No.*	Common Name	Scientific Name	Comments	References**
1	Acacia, mescat	*Acacia constricta*	Spiny shrub. Extremely drought tolerant. Adapted to a wide range of soils. Reported to be poisonous to livestock. Can be a weed on rangeland.	
2	Serviceberry, Western	*Amelanchier alnifolia*	Deep spreading root system. Fruit is excellent food for wildlife, including mountain quail, grouse, and mule deer.	71,111
3	Serviceberry, Utah	*Amelanchier utahensis*	Grows on dry sites. Prefers full sun. Good to excellent forage for sheep and goats.	73,111
4	Saltbrush, desert	*Atriplex polycarpa*	Easily established from direct seeding. Naturally forms pure stands on gravelly and sandy saline soils.	14,73
5	Saltbush, Australian	*Atriplex semibaccato*	Drought tolerant; semiprostrate habit. Supplemental irrigation needed to establish stands.	14
6	Pea shrub, Siberian	*Caragana arborescens*	Drought and alkali tolerant but will not tolerate wet soils. Long lived. Fixes nitrogen. Plants available in quantity. Extremely hardy and forms good windbreaks. Used widely in Northern Great Plains and north intermountain regions. Nesting site for birds.	14,52,73,107,111,116
7	Cassia, coves	*Cassia covesii*	Perennial legume. Normal height about 1 ft. Grows on rocky slopes up to about 3000 ft elevation.	73
8	Rabbitbrush, rubber	*Chrysothamnus nauseosus* sp.	Browsed by wildlife. Can be established from direct seeding and from transplants.	14,33,40,73,82,111
9	Rabbitbrush, alkali rubber	*Chrysothamnus nauseosus consimilis*	Browsed by wildlife. Can be established from direct seeding and from transplants.	82
10	Black bush	*Coleogyne* spp.	Good on sandy and gravelly soils. Thicket-forming. Much branched and wide spreading growth habit. Browse for sheep in winter.	14,27,73
11	Ephedra, green	*Ephedra viridis*	Small shrub. Grows up to 4 ft tall on rocky or sandy slopes (3000-7500 ft elevation). Can be established by direct seeding but seed available only from harvest of native plants. Browsed by deer and livestock.	14,73,111
12	Buckwheat, California	*Eriogonum fasciculatum* spp. *polifolium*	Grows on the poorest of dry slopes below 7000 ft elevation. Prime plant for honey bees. Commonly used on steep road cuts for erosion control. Browsed by deer and domestic livestock - hence should be fenced after planting.	14,73
13	Buckwheat, sulfur flowered	*Eriogonum umbellatum*	Shrubby to half-shrubby specie. Several varieties good for stabilizing problem soils. Food for upland and big game.	14,73
14	Rock-nettle	*Eucide urens*	Small, often decumbent shrub. Prefers full sunlight.	73
15	Paloblanco (New Mexico olive)	*Forestiera neomexicana*	Much branched and spreading shrub. Used mostly as an ornamental along roadsides. Not grazed by big game animals.	12,73
16	Ocotillo	*Fouquieria splendens*	Large shrub with simple stems. Flowers and fruit a source of food for American Indians.	14,73

(Continued)

* Numbers in column one of Table E-10 refer to the same species listed in column one of Table E-9.
** Numbers in column five refer to References at the end of this appendix.

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Table E-9 (Concluded)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
175	Cottonwood, eastern	*Populus deltoides*	X						X			X				4.5		O,P,Q,R,S,T,U,V,W,X, Y,Z	
176	Populars, hybrid	*Populus robusta*	X									X				5.0		R,S,T,U,V,W,X,Y,Z	
177	Oak, sawtooth	*Quercus acutissima*	X									X				5.0+		Q,V,Y,Z, and ZA	
178	Oak, white	*Quercus alba*	X									X				5.0		Q,S,T,U,V,W,X,Y,Z	
179	Red oak, northern	*Quercus rubra*	X									X				4.5		Q,V,X,Y,Z, and ZA	
180	Locust, black	*Robinia pseudocacia*	X	X					X			X				4.0			
181	Sassafras, white	*Sassafras albidum*	X						X			X				5.0		Q,S,T,U,V,W,X,Y,Z	
182	American holly	*Ilex opaca*			X								X			4.0		Q,V,X,Y,Z, and ZA	
183	Larch, Japanese	*Larix leptolepis*	X										X			4.0		O,R,S,T,W,X,Y	
184	Magnolia, evergreen	*Magnolia grandiflora*			X								X			4.0		Y,Z, and ZA	
185	Spruce, white	*Picea glauca*	X										X			5.0		R,T,U,W,X	
186	Pine, Caribbean	*Pinus caribaea*			X								X			4.5		ZA,ZB, and ZC	
187	Pine, shortleaf	*Pinus echinata*	X	X					X				X			4.0		Q,S,V,X,Y,Z, and ZA	
188	Pine, red	*Pinus resinosa*	X	X					X				X			4.0		T,U,W,X,Y	
189	Pine, pitch	*Pinus rigida*	X	X					X				X			4.0		W,X,Y	
190	Pine, white	*Pinus strobus*	X	X									X			4.5		R,S,T,U,X,Y	
191	Pine, loblolly	*Pinus taeda*	X		X								X			4.0		P,Q,S,V,Y,Z, and ZA	
192	Pine, Japanese black	*Pinus thunbergii*			X								X			5.5		T,U,V,X,Y	
193	Pine, Virginia	*Pinus virginiana*	X	X					X				X			4.0		V,X,Y,Z	
194	Oak, live	*Quercus virginiana*		X									X			~6.0		Q,V,Z,ZA, and ZB	

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil Humid: Acid	Region/Soil Humid: Excessively Drained	Region/Soil Humid: Poorly Drained	Region/Soil Arid and Semiarid: Saline Alkaline	Region/Soil Arid and Semiarid: Excessively Drained	Region/Soil Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
152	Grape, muscadine	*Vitus rotundifolia*		X										X		~5.0		Y	
153	Lantana, trailing	*Latana montevidensis*		X											X	~6.0		Y,Z	
154	Wedelia	*Wedelia trilobota*		X											X	~6.0		Y,Z,ZA,ZB	
155	Maple, red	*Acer rubrum*	X									X				4.5		P,Q,R,S,T,U,V,W,X,Y, Z, and ZA	
156	Maple, silver	*Acer saccharinum*	X	X					X			X				4.0		O,P,Q,R,S,T,U,V,W,X, Y,Z, and ZA	
157	Maple, sugar	*Acer saccharum*	X									X				~6.0		O,R,S,T,U,V,W,X,Y,Z	
158	Alder, European black	*Alnus glutinosa*	X	X					X			X				4.0		W,X	
159	Birch, river	*Betula nigra*	X		X							X				4.0		Q,S,T,V,W,X,Y,Z	
160	White birch, European	*Betula pendula*	X									X				3.5		O,R,T,U,W,X	
161	Birch, gray	*Betula populifolia*	X									X				3.5		V,W,X,Y	
162	Hickory, mockernut	*Carya alba*		X					X			X				5.5		Q,S,U,V,X,Y,Z, and ZA	
163	Chesnut, Chinese	*Castanea mollissima*	X	X					X			X				4.5		S,V,X,Y,Z	
164	Redbud	*Cercis canadensis*		X					X			X				6.0		S,T,U,V,X,Y,Z, and ZA	
165	Dogwood, flowering	*Cornus florida*	X									X				5.0		Q,S,T,U,V,X,Y,Z, and ZA	
166	Ash, white	*Fraxinus americana*	X									X				4.5		Q,S,T,U,V,X,Y,Z, and ZA	
167	Sweetgum	*Liquidambar styraciflua*	X	X					X			X				5.0		Q,S,V,X,Y,Z,and ZA	
168	Tulip tree	*Liriodendron tulipifera*		X								X				5.0		R,S,T,U,V,W,X,Y,Z	
169	Cucumber tree	*Magnolia acuminata*			X							X				4.0		S,U,W,X,Y,Z	
170	Crabapple, American	*Malus spp.*	X									X				5.0		P,S,U,V,X,Y,Z, and ZA	
171	Crabapple, American	*Malus coronaria*	X						X			X				~5.0		R,T,U,X,Y,Z, and ZA	
172	Sycamore	*Platanus occidentalis*	X									X				5.5		Q,R,S,U,V,W,X,Y,Z, and ZA	
173	Populars, hybrid	*Populus spp.*	X						X			X				5.0			
174	Popular, white	*Populus alba*		X					X			X				~5.0		S,V,X,Y,Z	

(Continued)

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
131	Willow, halbred	*Salix hastata*			X					X						~5.0			
132	Willow, sandbar	*Salix interior*			X					X						~5.0		O,Q,R,S,T,U,V,W,X,Y,Z, and ZA	
133	Osier, purple	*Salix purpurea*			X					X						4.5		S,V,X,Y,Z	
134	Pussywillow, dwarf	*Salix tristis*			X					X						~5.5		R,S,T,U,V,X,Y,Z	
135	Elderberry	*Sambucus canadensis*			X					X						~5.5		O,Q,R,S,T,U,V,W,X,Y, Z, and ZA	
136	Lilac	*Syringa vulgaris*	X						X	X						~5.5		W,X,Y	
137	Blueberry lowbush	*Vaccinium agnustifolium*		X						X						~4.5		S,T,U,W,X,Y	
138	Arrowwood, southern	*Viburnum dentatum*	X	X					X	X						4.5		S,T,U,V,W,X	
139	Wayfaring tree, rugose	*Viburnum lantana rugosum*		X						X						6.0		O,R,S,T,U,W,X	
140	Nannyberry	*Viburnum lentago*		X						X						~5.0		O,R,S,T,U,V,W,X,Y,Z	
141	Blackhaw	*Viburnum prunifolium*		X						X						~5.5		Q,S,T,U,V,X,Y,Z	
142a	Cranberry, bush American	*Viburnum trilobum*			X					X						6.5		O,R,S,T,U,V,W,X,Y,Z, and ZA	
142b	Cranberry highbush	*Viburnum trilobum*	X							X						4.5		R,S,T,U,W,X	
143	Barberry, wintergreen	*Berberris juliane*		X							X					~5.0		Y	
144	Bamboo	*Grundinaria*			X						X					~5.0		Y	
145	Inkberry or gallberry	*Ilex glabra*			X						X					5.0		W,X,Y,Z	
146	Holly, yaupon	*Ilex vomitoria*		X	X				X		X					~5.0		R,Y,Z, and ZA	
147	Juniper Pfitzer	*Juniperus chinensis Pfitzeriana*		X					X		X					~5.0		P,R,T,U,X,Y	
148	Privet, amur	*Ligustrum amurense*	X	X					X	X	X					4.5		O,P,R,S,T,U,V,W,X,Y,Z	
149	Myrtle, wax	*Myrica cerifera*		X	X						X					~5.0		Y,Z	
150	Trumpet creeper	*Campsis radicans*		X										X		~5.0		Y	
151	Creeper, Virginia	*Parthenocissus quinquifolia*		X										X		~5.0		X,Y	

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
110	Dogwood, red osier	*Cornus stolonifera*			X					X						4.5		O,R,S,T,U,V,W,X	
111	Silverberry	*Elaeagnus argentea*			X					X						~5.5		O,R,T,U,W	
112	Olive, autumn	*Elaeagnus umbellata*	X	X					X	X						4.0		R,S,T,U,V,W,X,Y	
113	Forsythia, Arnold dwarf	*Forsythia 'Arnold Dwarf'*		X					X	X						~5.5		V,X,Y,Z	
114	Greenweed, dyer's	*Genista tinctoria*		X						X						~5.0		X	
115	Winterberry	*Ilex verticillata*			X					X						5.0		T,U,V,W,X,Y,Z, and ZA	
116	Lespedeza, bicolor	*Lespedeza bicolor* var. 'Natob'	X						X	X						4.5		S,V,X,Y,Z	
117	Lespedeza, thunberg	*Lespedeza thunbergii*	X							X						4.5		S,V,X,Y,Z	
118	Honeysuckle Amur	*Lonicera maackii podocarpa* var. 'Rem Red'	X	X						X						5.5		S,T,U,V,X,Y	
119	Honeysuckle, Tatarian	*Lonicera tatarica sibirica*	X	X					X	X						4.5		R,S,T,U,V,W,X,Y,Z	
120	Sweet fern	*Myrica asplenifolia*		X						X						4.5		S,T,U,V,W,X,Y	
121	Bayberry	*Myrica pennsylvanica*	X							X						4.5		Q,U,W,X,Y,Z, and ZA	
122	Ninebark, eastern	*Physocarpus opulifolius*		X						X						~5.5		O,P,S,T,U,V,W,X,Y,Z, and ZA	
123	Sand cherry, western	*Prunus Besseyi*		X						X						5.0		O,P,T	
124	Sumac, fragrant	*Rhus aromatica*	X							X						4.5		Q,S,T,U,V,W,X,Y,Z, and ZA	
125	Sumac, shining	*Rhus coppalina*	X	X						X						4.5		Q,R,S,T,U,V,X,Y,Z, and ZA	
126	Sumac, smooth	*Rhus glabra*	X						X	X						4.0		O,P,Q,R,S,T,U,V,W,X,Y, Z, and ZA	
127	Sumac, staghorn	*Rhus typhina*		X						X						5.0		O,P,Q,R,S,T,U,V,W,Y,Z	
128	Locust bristly	*Robinia fertilis* var. 'Arnot'	X	X					X	X						3.5		S,T,U,V,X,Y	
129	Rose, acacia	*Robinia hispida*	X	X						X						4.0		V,X,Y	
130	Rose, rugosa	*Rosa rugosa* var's.	X	X						X						6.0		O,R,S,T,U,V,W,X,Y	

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
89	Box elder	*Acer negundo*	X				X		X			X				~5.5		O,P,Q,R,S,T,U,V,W,X,Y, Z, and ZA	
90	Tree-of-heaven	*Ailanthus altissima*		X			X		X			X				5.5	>18	O,S,U,V,X,Y,Z	B,C,I,K,N
91	Hackberry	*Celtis occidentalis*	X		X		X		X			X				~5.0	14-20+	O,Q,R,S,T,U,V,W,X,Y,Z, and ZA	A,B
92	Ash, green	*Fraxinus pennsylvanica*			X		X					X				4.5	16-20+	Q,R,S,T,U,V,W,X,Y,Z, and ZA	A,B,C,E,I
93	Ash, green	*Fraxinus pennsylvanica* var. *lanceolata*	X				X		X			X				4.5	16-20+	O,Q,R,S,T,U,V,W,X,Y,Z	A,B,C,E,I
94	Honey locust, thornless	*Gleditsia triacanthos* var. *inermis*			X		X		X			X				6.5	>18	Q,S,T,U,V,W,X,Y,Z, and ZA	A,B,C,I
95	Popular, Lombardy	*Populus nigra* var. 'Italica'	X	X		X	X		X			X				5.0	12-20+	O,R,T,U,V,W,X,Y	A,B,D,E,G,H,I
96	Juniper, Rocky Mountain	*Juniperus scopulorum*	X			X			X				X			~5.0	12-20+	O,P,R,S	A,B,D,E,F,H,J
97	Cedar, eastern red	*Juniperus virginiana*	X	X			X		X				X			5.0	17-20+	O,Q,R,S,T,U,V,W,X,Y,Z	A,B
98	Spruce, Norway	*Picea abies*	X			X			X				X			4.0	16-20+	R,T,U,W,X	C,K,L,M,N
99	Pine, Austrian	*Pinus nigra*	X	X			X		X				X			4.0	>18	R,S,T,U,V,W,X,Y	A,B,G,H,I
100	Pine, scotch	*Pinus sylvestris*	X	X			X		X				X			4.0	>16+	R,S,T,V,W,X,Y,Z	A,B,G,H,I
101	Alder, tag	*Alnus rugosa*			X					X						NA		Q,S,T,U,V,W,X,Y,Z	
102	Service berry	*Amelanchier oblongifolia*		X						X						~5.0		O,R,S,T,U,V,W,X,Y,Z	
103	Indigo bush	*Amorpha fruticosa*	X	X						X						4.0		O,P,Q,R,S,T,U,V,W,X, Y,Z	
104	Indigo, mountain	*Amorpha glabra*		X						X						~5.0		X,Y,Z, and ZA	
105	Chokeberry, black	*Aronia melanocarpa*			X					X						~5.5		S,T,U,V,W,X,Y,Z	
106	Pepperbush, sweet	*Clethra alnifolia*			X					X						5.0		W,X,Y,Z, and ZA	
107	Dogwood, silky	*Cornus amomum*	X	X					X	X						4.5		O,R,S,T,U,V,W,X,Y,Z and ZA	
108	Dogwood, gray	*Cornus paniculata*		X						X						6.0		R,S,T,U,V,W,X,Y,Z	
109	Dogwood, gray	*Cornus racemosa*			X					X						~5.0		R,S,T,U,V,W,X,Y,Z	

(Continued)

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil, Humid: Acid	Region/Soil, Humid: Excessively Drained	Region/Soil, Humid: Poorly Drained	Region/Soil, Arid and Semiarid: Saline Alkaline	Region/Soil, Arid and Semiarid: Excessively Drained	Region/Soil, Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
66	Ash, white	*Fraxinus americana* var. *microcarpa*					X		X			X					18-20+		A,B,E,I
67	Ash, velvet	*Fraxinus velutina*					X		X			X					13-20+		C,F,I,K,N
68	Ash, velvet (desert ash)	*Fraxinus velutina coriacea*						X				X					11-20+		C,F,I,K,N
69	Honey locust	*Gleditsia triacanthos*					X					X					16-20+		A,B,C,I
70	Mulberry, Russian	*Morus alba*					X					X					16-20+		B,C
71	Mulberry, weeping	*Morus alba* var. 'Kingan'				X			X			X					12-20+		A,B,E,K,I
72	Mesquite, Chile	*Prosopis chilensis*				X						X					8-18+		K,N
73	Oak, Gambel	*Quercus gambelii*					X					X					14-20+		E,F,I,K
74	Willow, golden	*Salix alba vitellina*						X				X					8-12		Nevada
75	Tamarisk	*Tamarix gallica*				X			X			X					12-20+		B,C,E,I,J,K,L,M,N
76	Elm, Siberian	*Ulmus pumila*					X		X			X					12-20+		A,B,E,F,I,K
77	Joshua tree	*Yucca brevifolia* var. *herbertii*					X						X‡				7-10		N
78	Yucca, Mojave	*Yucca schidigera*					X						X‡				7-14		N
79	Mahogany, mountain	*Cercocarpus montanus*					X						X				10-20+		A,B,D,E,F,I,J,K
80	Eucalyptus, yatetree	*Eucalyptus cornuta*				X			X				X				10-20+		M,N
81	Eucalyptus, bluegum	*Eucalyptus globulus*				X			X				X				10-20+		M,N
82	Cypress, Arizona	*Cupressus arizonica*					X		X				X				16-20+		F,K,M,N
83	Red cedar, Rocky Mountain	*Juniperus scopulorum*						X					X				10-20+		A,B,D,E,F,I,J,K
84	Pine, pinyon	*Pinus edulis*					X						X				12-16		B,E,F,I,K
85	Pine, Aleppo	*Pinus halepensis*				X			X				X				18-20+		C,K,L,M,N
86	Pine, ponderosa	*Pinus ponderosa*					X		X				X				11-20+		A,D,E,F,J,K,L
87	Bearberry	*Arctostaphylos uva-ursi*	X	X			X								X	4.5	16-20+	O,P,Q,R,S,T,U,V,W,X, Y,Z	A,B,D,E,F,G,H,I,J,L,M
88	Juniper, creeping	*Juniperus horizontalis*		X			X				X					~5.0	12-20+	O,R,T,V,W,X,Y	A,D

(Continued)

‡ Succulent trees.

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
43	Yerba-santa, narrow-leaf	*Eriodictyon angustifolium*					X				X						6-16		I,J,K
44	Winterfat	*Eurotia lanata*				X	X		X		X						6-15+		A,B,E,F,G,H,I,J,K,L, M,N
45	Bursage, triangle	*Franseria deltoides*					X				X						6-12		N
46	Bursage, white	*Franseria dumosa*				X					X						<6-12+		I,N
47	Bladderpod	*Isomeris arborea*				X					X						10-20+		I,M,N
48	Junipers (shrub forms)	*Juniperus communis*				X			X		X						16-20+		A,D,E,J,K,L
49	Juniper, cherrystone	*Juniperus monosperma*					X		X		X		X						
50	Creosote bush	*Larrea divaricata*				X					X						6-14+		N
51	Oleander	*Nerium oleander*				X			X		X						8-16		C,K,N
52	Pea, chaparral	*Pickeringia montana*					X				X						14-20		L
53	Antelope brush	*Purshia tridentata*					X		X		X						12-20+		D,E,F,G,H,I,J,K,L
54	Firethorn	*Pyracantha coccinea*				X			X		X						16-20+		B,C,F,K
55	Sumac, mahogany	*Rhus integriflora*					X				X						6-16		N
56	Jojoba (Goat nut)	*Simondsia chinensis*					X				X						10-16		N
57	Acacia, catclaw	*Acacia greggii*					X					X					8-17		B,C,I,K,N
58	Acacia, catclaw	*Acacia tortuosa*					X		X			X					8-17		B,C,I,K,N
59	Birch, water	*Betula occidentalis*						X				X					12-15		I,J,K,L
60	Desert willow	*Chilopsis linearis*					X					X					8-14		B,C,I,K,N
61	Desert willow	*Chilopsis linearis* var. 'Barranco'					X		X			X					8-14		B,C,I,K,N
62	Hawthorn, fireberry	*Crataegus chrysocarpa*					X		X			X					15-20+		A,B
63	Hawthorn western, black	*Crataegus douglasii*					X					X					12-20+		Idaho, Nevada, E. Washington, and E. Oregon
64	Russian olive	*Elaeagnus*					X				X	X					10-20+		A,B,E,F,G,H,I,J,K
65	Russian olive	*Elaeagnus angustifolia*				X	X		X		X	X					10-20+		A,B,E,F,G,H,I,J,K

(Continued)

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Table E-9 (Continued)

No.	Name: Common	Name: Scientific	Region/Soil: Humid: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance	Annual Precipitation Tolerance Range, in.	Recommended Plant Growth Regions: Humid	Recommended Plant Growth Regions: Arid and Semiarid
21	Dune broom	*Parryella filifolia*				X	X		X	X							6-13		K
22	Fleabane	*Pluchea sericea*						X		X							12-16		I,J,K
23	Milkwort	*Polygala subspinosa*					X			X									Nevada
24	Plum, wild	*Prunus americana*				X			X	X							16-20+		A,B,C,D,E,F
25	Peach, desert	*Prunus andersonii*					X			X							14-20		I,L
26	Almond, desert	*Prunus fasiculata*					X			X									E,I,J,K,M,N
27	Sumac, lemonade	*Rhus trilobata*				X	X		X	X							11-19		A,B,C,D,E,F,G,H,I,J, K,L,M,N
28	Buffaloberry, silver	*Shepherdia argentea*				X			X	X							16-20+		A,B,D,E,I,J,K,L
29	Snow berry	*Symphoricarpos albus*					X			X							8-12		E,E,F,G,H,I,K,L,M
30	Grape, Long's	*Vitis Longii*					X			X							8-18		A,B,C,K
31	Fourwing saltbush	*Atriplex canescens*				X	X	X	X		X						6-16		A,B,E,F,G,H,I,J,K,L, M,N
32	Holly, desert	*Atriplex hymenelytra*					X				X						6-12		N
33	Quail bush	*Atriplex lentiformis*				X					X						6-14+		I,K,L,M,N
34	Salthush nuttall	*Atriplex nuttallii*				X					X						6-15+		A,F,G,H,I,J
35	Hollygrape, Fremont	*Berberis freemontii*					X				X						6-16		E,F,I,J,K,N
36	Hackberry, spiny	*Celtis pallida*					X		X		X						8-14		B,C,K,N
37	Mountain mahogany, curl leaf	*Cercocarpus ledifolius*					X				X						8-18		A,D,E,F,I,J,L,N
38	Quinine bush	*Cowania mexicana stansburiana*					X				X						6-16		E,F,I,J,K
39	Brittlebush, white	*Encelia farinosa*					X				X								Death Valley, East Mojave Desert, Southwest Utah, and Arizona
40		*Ephedra fasiculata*					X				X						6-10		N
41		*Ephedra funerea*					X				X						6-12		N
42	Popotillo	*Ephedra trifurca*					X				X						6-12		K,N

(Continued)

(Sheet 2 of 9)

Table E-9

Characteristics and Suitability of Shrubs and Trees Recommended for Establishing Ground Cover

No.*	Name: Common	Name: Scientific	Region/Soil: Acid	Region/Soil: Humid: Excessively Drained	Region/Soil: Humid: Poorly Drained	Region/Soil: Arid and Semiarid: Saline Alkaline	Region/Soil: Arid and Semiarid: Excessively Drained	Region/Soil: Arid and Semiarid: Poorly Drained	Wind Erosion Control	Shrubs: Deciduous	Shrubs: Evergreen	Trees: Deciduous	Trees: Evergreen	Ground Cover: Deciduous	Ground Cover: Evergreen	Lower pH Tolerance**	Annual Precipitation Tolerance Range, in.†	Recommended Plant Growth Regions††: Humid	Recommended Plant Growth Regions††: Arid and Semiarid
1	Acacia, mescat	*Acacia constricta*					X			X							11-16+		N
2	Serviceberry, Western	*Amelanchier alnifolia*					X			X							14-20+		A,D,E,F,K,L,N
3	Serviceberry, Utah	*Amelanchier utahensis*					X			X							6-12		G,H,I,J,K
4	Saltbush, desert	*Atriplex polycarpa*				X				X							6-16+		K,L,M,N
5	Saltbush, Australian	*Atriplex semibaccato*				X				X							8-14		K,M,N
6	Pea shrub, Siberian	*Caragana arborescens*				X			X	X		X					12-20+		A,D,E,F,G,H,I,J,L
7	Cassia, Coves	*Cassia covesii*					X			X							11-16+		N
8	Rabbitbrush, rubber	*Chrysothamnus nauseous* sp.					X			X							8-18		A,B,D,E,F,G,H,I,J,L
9	Rabbitbrush, alkali rubber	*Chrysothamnus nauseosus consimilis*				X				X							8-18+		A,B,D,E,F,G,H,I,J,L
10	Black bush	*Coleogyne* spp.					X			X							6-12		I,J,K
11	Ephedra, green	*Ephedra viridis*					X			X							6-14+		F,I,J,K,N
12	Buckwheat, California	*Eriogonum fasciculatum* spp. *polifolium*					X		X	X							7-13		M,N
13	Buckwheat, sulfur flowered	*Erigonum umbellatum*					X			X							10-20+		G,H,I,J,K,L
14	Rock-nettle	*Eucide urens*					X												I,J,N
15	Paloblanco (New Mexico olive)	*Forestiera neomexicana*				X		X		X							9-18+		B,C,E,F,I,K,L,N
16	Ocotillo	*Fouquieria splendens*					X			X									B,K,N
17	Molly, green	*Kochia americana*				X		X		X							8-18+		I,J
18	Seale broom	*Lepidospartum squamatum*					X			X							6-12		N
19	Mendora, rough	*Mendora scabra*					X			X									Nevada
20	Dalea, Fremont	*Parosela fremontii*					X			X							6-12		I,J,K,N

(Continued)

* Numbers in column one of Table E-9 refer to the same species listed in column one of Table E-10.

** pH values listed refer to the lowest pH value at which the specie will grow sufficiently to produce an acceptable ground cover.

† Range in precipitation applies only to arid and semiarid regions.

†† Letters refer to areas shown in Figures V1 and V2 of main text.

(Sheet 1 of 9)

Table E-8 (Concluded)

No.	Common Name	Scientific Name	Comments	References
41	Clover, Persian	*Trifolium resupinatum*	Rapid growth in spring smothering out other plants. Dies early. Causes bloat in cows. Grows best on heavy alluvial soils. Spreading growth habit similar to white clover.	32,41
42	Cowpea	*Vigna sinensis*	Good green manure plant. Reseeding varieties are: Torsby cream, Tory, and Wikos. Choice food of turkeys, quail, and songbirds. Young plants may be destroyed by deer. Plants and seed are choice food of deer.	32,41,69,107
43	Yarrow, common	*Achillea millefolium*	Forms practically evergreen ground cover. Grows well in very poor, dry soils (6 in. to 2 ft). Propagation is by division of roots or self-sown seed. Forms ground cover when mowed.	72,82,111,113
44	Yarrow, wooly	*Achillea tometosa*	Grows well in infertile dry soil. Practically evergreen ground cover when mowed.	
45	Coreopsis, dwarf eared	*Coreopsis auriculata*	Propagated from seed and plant division. Grows to 6 in. tall. Blooms profusely in summer.	32,72
46	Buckwheat	*Fagopyrum* spp.	Temporary cover crop. Grows rapidly to about 2 ft high on soils with a wide range in texture. Seed provide food for upland game birds and rodents. May poison livestock that have unpigmented skin.	14,69,82,107
47	Sunflower, swamp	*Helianthus angustifolius*	Adapted to wet and dry areas except in coarse sands and loess (silts). Grows 1-7 ft. Provides seed for upland game birds and rodents. Flowers from August to October.	69
48	Sunflower, annual	*Helianthus annuus*	Native, herbaceous specie that grows 6-7 ft tall. Flowers from August to October. Propagated by seed. Seed provide food for birds and rodents.	69,108
49	Daylily	*Hemerocallis fulva* var. *'Europa'*	Extends rhizomes in all directions; good soil stabilizer. Propagated by rhizome division. Does not set seed. Grows up to 6 ft tall.	41
50	Fleeceflower, Japanese	*Polygonum cupsidatum*	Can be direct seeded. Volunteers readily, is an aggressive colonizer of disturbed lands, and could become a pest on farmlands. Grows robustly to 6-8 ft tall in one season. Dies back each year and new growth arises from root stocks and rhizomes. Prolific seed producer. Foliage turns red in autumn.	41,107
51	Knotweed	*Polygonum muhlenbergii*	Easily propagated by seed, some by division of plants. Reseeds readily. All seeds remain viable for years in wet soil or under water. Seed is a choice food of most wild ducks and is also eaten by nongame birds. Another important perennial is *P. hydropiperoides* (mild water pepper).	
52	Smartweed	*Polygonum pennsylvanicum*	Similar to *P. labathifolium*; both root readily wherever stems touch the ground. Seeds are choice foods of wild ducks and nongame birds.	
53	Germander chamedrys	*Teucrim chamaedrys*	Propagated either by seed or plant division. Grows about 10 in. tall. Good ground cover.	41

(Sheet 4 of 4)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
70	Mulberry, Russian	*Morus alba*	Rapid growing. Grows well on either moist or dry soils in its range. Fruit eaten by upland game birds	54,73
71	Mulberry, weeping	*Morus alba* var. 'Kingan'		
72	Mesquite, Chile	*Prosopis chilensis*	Value for stabilizing problem soils. Transplants appear better than direct seeding. Excellent forage plant. Seed eaten by many birds.	
73	Oak, Gambel	*Quercus gambelii*	Small tree. Prefers dry, sunny sites. Resistant to heavy grazing. Acorns eaten by wild turkeys.	73
74	Willow, golden	*Salix alba vitellina*	Prefers moist sites. Occurs mostly on loamy sands or sandy loam soils. Has pendant branches. Can be grown as a hedge.	54,73
75	Tamarisk	*Tamrix gallica*	Thicket-forming small tree. Very drought tolerant. Withstands alkaline conditions well. Grows rapidly from cuttings. Fruit used as food by 11 bird species and Texas fox squirrels.	33,54,73,113
76	Elm, Siberian	*Ulmus pumila*	Fast-growing, semidrought resistant, large tree. Plant material available commercially. Widely used in windbreaks.	52
77	Joshua tree	*Yucca brevifolia* var. *herbertii*	Succulent tree. Easily grown from seed. Grows in Mojave Desert between 1900 and 5900 ft elevations. Nesting site for nine species of birds.	14,73
78	Yucca, Mojave	*Yucca schidigera*	Succulent tree. Easily grown from seed. Grows on a wide range of dry soil conditions.	14,73
79	Mahogany, mountain	*Cercocarpus montanus*	Evergreen only in southern part of its range. Valuable for stabilizing problem soils.	52,82,111
80	Eucalyptus, yatetree	*Eucalyptus cornuta*	Excellent drought resistance. Established by cuttings. Poisonous to grazing animals if eaten in quantity.	
81	Eucalyptus, blue gum	*Eucalyptus globlus*	Fast-growing. Excellent drought resistance. Established by cuttings. Widely used for windbreaks. Reported poisonous to grazing animals if eaten in quantity.	54
82	Cypress, Arizona	*Cupressus arizonica*	Shade intolerant. Rapid growing in fertile soils. Long lived. Grows well on gravelly slopes and cuts. Susceptible to fire.	12,54,73
83	Red cedar, Rocky Mountain	*Juniperus scopulorum*	Slow-growing. Long lived. Tolerates calcareous sites. Occurs at 6000-8500 ft elevation naturally. One ecotype grows in wet and saline bottoms, associated with greasewood and rabbit brush.	12,33,52,71,73,111
84	Pine, pinyon	*Pinus edulis*	Very slow-growing. Prefers dry, sunny sites. Very drought resistant. Seeds eaten by game birds and animals.	14
85	Pine, Aleppo	*Pinus halepensis*		54
86	Pine, ponderosa	*Pinus ponderosa*	Shade intolerant. Prefers dry soils. Seed eaten by porcupine and squirrels. Excellent browse for deer. Long lived.	12,52,71,73,82,107,111
87	Bearberry	*Arctostaphylos uva-ursi*	Drought resistant, native specie that is adapted to both humid and semiarid conditions. Requires full sunlight. Thrives in poor droughty sands and sandy calcareous soils.	116,117

(Continued)

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Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
88	Juniper, creeping	*Juniperus horizontalis*	Prostrate evergreen adapted to humid and semiarid regions. Grows best on sands. Forms dense mats and stabilizes sandy soils. Fruit used by birds throughout the year. Browsed sparingly. Available in different colors and matting characteristics.	71,73,82
89	Box elder	*Acer negundo*	Rapid-growing. Short lived. Shade intolerant. Easily damaged in storms. Shoots emerge on exposed or injured roots.	52,54,71,73,112,113
90	Tree-of-heaven	*Ailanthus altissima*	Rapid-growing. Forms coppices freely. Shade intolerant. Adapted to both humid and semiarid conditions. Grows well on infertile soils. Easily damaged by ice storms. Immune to insect damage.	54
91	Hackberry	*Celtis occidentalis*	Rapid-growing, short-lived small tree that is very drought resistant and tolerates shade. Medium deep to shallow root system. Young plants easy to transplant. Scarify seed. Several varieties available. Adapted to both humid and semiarid conditions.	31,52,71,113
92	Ash, green	*Fraxinus pennsylvanica*	Native tree with shallow root system. Adapted for both humid and semiarid regions. Rapid growing when young. Confined mostly to bottom lands in midwest. Coppices do not develop into large trees. Does well on clear-tilled windbreaks in the central and Northern Great Plains.	31,54,69,107,111,112,113
93	Ash, green	*Fraxinus pennsylvanica* var. *lanceolata*	Long lived with shallow and wide-spreading root system. Adapted to both humid and semiarid conditions. Rapid growing--especially when young. Generally free from diseases. *Excellent* shelter belt tree in Great Plains. Used on slopes and graded banks with compact clays. Can be planted in mixtures of other hardwoods. Intermediate shade tolerance.	31,54,71,73,107
94	Honey locust, thornless	*Gleditia triacanthos* var. *inermis*	Shade intolerant, rapid-growing, long lived, legume. Deep rooted. Shrub or tree. Forms coppices freely. Excellent windbreak tree. Grafted sections available commercially. Pods eaten by upland game animals. Adapted to both humid and semiarid conditions.	27,43,52,54,71,73,113
95	Poplar, Lombardy	*Populus nigra* var. 'Italica'	Quick growing tree used for temporary windbreaks. Cut down before tops die back fully. Adapted to both humid and semiarid conditions.	54,73
96	Juniper, Rocky Mountain	*Juniperus scopulorum*	Long-lived tree that tolerates shade only during seedling and early sapling stages. Adapted to both humid and semiarid conditions. Has shown good survival on Kansas mine soils. Fruit persists all year. More commonly found east of the continental divide.	12,33,52,71,73,107,111
97	Cedar, eastern red	*Juniperus virginiana*	Shade intolerant, long-lived, slow-growing tree adapted to both humid and semiarid conditions. Grows best on dry sandy soils mixed in with black locust. Superior to Rocky Mt. Juniper in western Oklahoma and western Texas at low elevations. Above 3500-4000 ft elevations, Rocky Mountain Juniper superior.	12,31,43,52,54,69,71,73,82,107, 111,112,116,117
98	Spruce, Norway	*Picea abies*	Shade tolerant. Fast-growing when young. Very cold resistant. Good windbreak tree. Adapted to both humid and semiarid conditions.	54,69,107

(Continued)

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Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
99	Pine, Austrian	*Pinus nigra*	Grows well on infertile soils. Performs best in Central Great Plains. Can be planted on all slopes. Plant in bands or blocks. Do not plant near black locust as deer will cause browse damage. Adapted to both humid and semiarid conditions.	43,54,69,71,107,117
100	Pine, scotch	*Pinus sylvestris*	Shade intolerant. Tolerates acid soils. Drought resistant. Performs well on infertile medium sands. Best transplanted as either balled and burlapped or from container-grown stock. Performs best in Central Great Plains. Can be planted on all slopes. Plant in bands or blocks. Used in windbreaks. Adapted to both humid and semiarid conditions.	43,69,71,107,116,117
101	Alder, tag	*Alnus rugosa*	Forms thickets. Large shrub with very thick foliage. Nutlets are eaten by upland game birds and white-tailed deer.	
102	Service berry	*Amelanchier oblongifolia*	Large shrub, often clump-forming. Fruit seeds eaten by game birds, deer, and browsed by moose. Variety 'Micropetala' is a dwarf on exposed, dry ledges.	73
103	Indigo bush	*Amorpha fruticosa*	Intermediate shade tolerance but prefers full sun. Legume. Tolerant to acid soils but often occurs on calcareous soils. Large shrub. Slow spreader; thicket former. Fruit eaten by quail. Forage not palatable to livestock.	27,43,52,82,107,111,116,117
104	Indigo, mountain	*Amorpha glabra*	Legume. Prefers full sun. Adapted to a wide range of soils. Propagated by seed or greenwood cuttings.	117
105	Chokeberry, black	*Aronia melanocarpa*	Shade tolerant. Adapted to dry soils. Fruit (berry) is eaten by upland game birds including grouse.	71,82,107
106	Pepperbrush, sweet	*Clethra alnifolia*	Tolerates shade but prefers full sun. Grows well on sandy soils in the South.	71,117
107	Dogwood, silky	*Cornus amomum*	Small to large shrub. Shade tolerant. Provides food and cover for upland game birds.	27,43,71,107
108	Dogwood, gray	*Cornus paniculata*	Small shrub. Tolerates shade. Forms dense thickets. Easily propagated by seed. Important food for game and nongame birds.	
109	Dogwood, gray	Cornus racemosa	Tolerates shade; forms extremely dense thickets. Successful on problem sites wet or dry. Fruit (drupe) eaten by upland game birds.	43,71,107,116
110	Dogwood, red osier	*Cornus stolonifera*	Thicket-forming by root stocks. Tolerates shade and alkaline soil. Fruit (drupe) eaten by upland game birds.	14,31,33,52,71,73,107,112,113, 116,117
111	Silverberry	*Elaeagnus argentea*	Forms thickets; spreads by underground stolons. Will grow on calcareous soils. Shade tolerant.	33
112	Olive, autumn	*Elaeagnus umbellata*	Fixes nitrogen. Good for erosion control and wildlife habitat. Establish in mixed plantings with hardwoods. Wide adaption.	14,71,82,107,116,117
113	Forsythia, Arnold dwarf	*Forsythia* 'Arnold Dwarf'	Procumbent branches will root whenever they touch moist soils. Survives on slopes and rocky soils. Develops a dense mat of foliage in a short period of time. Excellent woody cover plant. Adapted to a wide range of soils.	71,82,110,116,117

(Continued)

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Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
114	Greenweed, dyer's	*Genista tinctoria*	Small leguminous shrub. Free from insects and diseases. Prefers full sunlight. Sets seed two seasons after planting and establishes itself naturally. Thrives on dry, infertile soils. Propagated by seed.	116,117
115	Winterberry	*Ilex verticillata*	Easily transplanted; free from insects and diseases. Fruit (berry) is eaten by upland game birds.	71,116,117
116	Lespedeza, bicolor	*Lespedeza bicolor* var. 'Natob'	Shade intolerant. Does well on sandy soils. Established from transplants or can be direct seeded in bands but must be mixed with suitable erosion control ground cover. May grow to 9 ft tall. Not an effective erosion control plant, especially on silt loams and clay soils.	27,43,116,117
117	Lespedeza, thunberg	*Lespedeza thunbergii*	Less hardy than *L. bicolor*, but provides seed and habitat for wildlife equal to *L. bicolor*.	43,108
118	Honeysuckle, Amur	*Lonicera maackii podocarpa* var. 'Rem Red'	Good for wildlife food and cover. Vigor and adaptability improve as plants improve.	12,43,71,107
119	Honeysuckle, Tatarian	*Lonicera tatarica siberica*	Very hardy and vigorous with upright growth habit. Forms clumps. Grows best on well-drained soils. Intermediate shade tolerance. Takes 2 years to form good cover. Generally unpalatable to livestock. Fruit used by game birds, chipmunks, and moose.	43,52,71,73,82,107,116,117
120	Sweet fern	*Myrica asplenifolia*	Small shrub. Often forms very dense colonies in the wild. Pioneer species in burned-over areas to the north. Fruit used by birds and deer.	73,82
121	Bayberry	*Myrica pennsylvanica*	May be broadcast or spot seeded on 4-ft centers in spring or fall in Massachusetts. Spreads by stolons. Thicket-forming. Fixes nitrogen. Prefers sunny areas with no competition from other plants. Waxy nutlike fruit widely used by birds.	14,41,43,71,82,116,117
122	Ninebark, eastern	*Physocarpus opulifolius*	Fast-growing, small to large shrub. Several good varieties are available. Good for wildlife food and cover.	33,43,71
123	Sand cherry, western	*Prunus Besseyi*	Small, more or less prostrate shrub. Sprouts from roots but does not form thickets. Good wildlife food and cover. May be poisonous to cattle.	52,73,108
124	Sumac, fragrant	*Rhus aromatica*	Intermediate shade tolerance. Adapted to a wide range of soils including limestone soils. Forms thickets.	43,71,107,113,116,117
125	Sumac, shining	*Rhus coppalina*	Drought resistant, small to large shrub with intermediate shade tolerance. Forms thickets. Good for game birds and deer.	43,107,112,116,117
126	Sumac, smooth	*Rhus glabra*	Intermediate to intolerant to shade. Grows best in slightly acid soils. Tolerates poorly drained soils. Commonly forms thickets. Small to large straggling shrub. Preferred food of wild turkeys.	31,33,41,43,73,116,117
127	Sumac, staghorn	*Rhus typhina*	Sprouts persistently from the roots after injury. Forms loose thickets. Browsed by deer and moose. Food for game birds.	31,71,73,112,116,117

(Continued)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
128	Locust, bristly	*Robinia fertilis*, var. 'Arnot'	Shade intolerant. Thicket former. Grows 5-7 ft tall. Can be direct seeded. Vigorous. Fixes nitrogen. Tolerant to very acid soils. Good for erosion control on steep slopes as well as flat areas. Provides good wildlife cover.	14,43,82,107,116,117
129	Rose acacia	*Robinia hispida*	Shade and drought tolerant, spiny legume. Spreads by stolons. Small to large shrub. Propagated extensively from suckers. Adapted to a wide range of soils.	31,107
130	Rose, rugosa	*Rosa rugosa* and cultivars	Shade intolerant. Very hardy. Somewhat salt tolerant. Rose hips are food for ruffed grouse, deer, and opossum. Autumn foliage is bright orange.	5,43,71,107,116,117
131	Willow, halbred	*Salix hastata*	Dwarf willow; grows 5 ft tall. Lower limbs hug the ground and take root. Adapted to infertile soils.	
132	Willow, sandbar	*Salix interior*	Forms thickets by underground stolons. Prefers full sun. Fruit (capsule) eaten by white-tailed deer.	33
133	Osier, purple	*Salix purpurea*	Successfully established on problem soils in central Appalachia. Shade intolerant.	33,71,107,116,117
134	Pussywillow, dwarf	*Salix tristis*	Grows on dry, well-drained soils. Prefers full sunlight.	
135	Elderberry	*Sambucus canadensis*	Tolerates shade. Berries eaten by upland game birds and white-tailed deer.	
136	Lilac	*Syringa vulgaris*	Vigorous growing. Forms dense clusters via root suckers. Grows to 20 ft high. Prefers full sunlight but tolerates 50 percent shade.	14,43,73
137	Blueberry, lowbush	*Vaccinium angustifolium*	Spreads by underground stems. Earliest ripening blueberry. Fruit eaten by birds and small animals.	73,116,117
138	Arrowwood, southern	*Viburnum dentatum*	Thicket-forming and shade tolerant. Easily propagated from cuttings.	31,43,71,116,117
139	Wayfaring tree, rugose	*Viburnum lantana rugosum*	Very tolerant of dry soils. Raisinlike fruits used by game birds and deer.	71
140	Nannyberry	*Viburnum lentago*	Multiplies freely by suckers. Easily propagated by cuttings. Food for ruffed grouse, pheasants, rabbits, and goats.	43,71,117
141	Blackhaw	*Viburnum prunifolium*	Large shrub. Tolerates shade and moist sites. Valuable food for birds including bobwhite quail, deer, and gray fox. Cover for birds.	31,43,71
142 (a)	Cranberry bush, American	*Viburnum trilobum*	Tolerates shade. Fruit (drupe) is eaten by upland game birds.	116
142 (b)	Cranberry highbush	*Viburnum trilobum*	Large shrub. Grows well in sun or shade. Prefers moist soils. Drupe eaten by upland game birds.	
143	Barberry, wintergreen	*Berberis*		9,31,71,73,82,107,111,112
144	Bamboo	*Grundinaria*	Tolerates 50 percent shade. Slow to establish but makes dense cover in 2-3 years. Spreads well by underground stolons. Very drought tolerant.	

(Continued)

(Sheet 9 of 13)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
145	Inkberry, gallberry	*Ilex glabra*	Slow grower. Sometimes bothered by scale insects. Will sprout after fire. Berry eaten by upland game birds.	82,112,116,117
146	Holly, yaupon	*Ilex vomitoria*	Shade intolerant. Large shrub--rarely a small tree. Adapted to sandy soils. Considered the most drought resistant holly. Spreads slowly by occasional sprouts from root suckers. Red berries eaten by birds.	31
147	Juniper, Pfitzer	*Juniperus chinensis* 'Pfitzeriana'	Slow-growing and very compact. Drought and cold resistant. Grows well in sands and sandy soils. Provides cover and nesting sites for birds.	12,41,71,116
148	Privet, amur	*Ligustrum amurense*	Evergreen in warm areas; deciduous in cold areas. Shade intolerant and very hardy. Good erosion control plant. Fruit eaten by bobwhite quail and many species of song birds.	43,107,116
149	Myrtle, wax	*Myrica cerifera*	Will tolerate shade and grow on sand dunes. Low nutrient requirement. Fruit eaten by upland game birds.	
150	Trumpet creeper	*Campsis radicans*		31
151	Creeper, Virginia	*Parthenocissus quinquifolia*		33,41,52,116
152	Grape, muscadine	*Vitis rotundifolia*		
153	*Lantana*, trailing	*Lantana montevidensis*	Makes rapid growth in spring after winterkill. Has a low fertilizer requirement. Grows best on sandy soils.	
154	Wedelia	*Wedelia trilobota*	Tolerates 50 percent shade well. Very tolerant of soil salinity and drought. Propagated by cuttings or natural layering. Frost kills plant tops but recovery is extremely vigorous in spring.	
155	Maple, red	*Acer rubrum*	Tolerates intermediate shade. Grows rapidly on both wet and dry soils. Very adaptable. Forms coppices freely, especially when young. Seed eaten by 10 species of birds, deer, chipmunks, and rabbits.	31,54,69,71,107,112,113
156	Maple, silver	*Acer saccharinum*	Shade tolerance--intermediate to intolerant. Forms coppices freely. Grows well on acid and somewhat poorly drained soils. Grows fast at first. Plant in mixtures of other hardwoods such as red oak.	69,71,73,107,113
157	Maple, sugar	*Acer saccharum*	Shade tolerant. Shallow and wide-spreading root system. Long-lived tree. Seed eaten by white-tailed deer and moose.	31,43,54,69,71,107,113
158	Alder, European black	*Alnus glutinosa*	Shade intolerant. Rapid-growing. Fixes nitrogen but not as much as black locust. More tolerant of acid soils than black locust. Adapted to all slopes. Fruit eaten by ruffed grouse.	54,69,107,113
159	Birch, river	*Betula nigra*	Short lived, rapid-growing when young (growth rate comparable to sycamore), forms coppices freely when cut and has intermediate shade tolerance. Small nutlets eaten by deer and turkeys. Well adapted to central Appalachians, eastern Ohio and Kentucky.	31,69,71,107,113
160	White birch, European	*Betula pendula*	Grows best on moist, well-drained sites. Large tree--up to 60 ft. Shade intolerant.	54,69

(Continued)

(Sheet 10 of 13)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
161	Birch, gray	*Betula populifolia*	Shade intolerant. Grows fairly fast. Short lived. Forms coppices freely when cut. Good for deer browse.	108,113
162	Hickory, mockernut	*Carya alba*	Shade intolerant. Wind-firm, strong taproot, and rapid-growing when young. Stump and root sprouts produced freely. Nuts valuable for wildlife.	108,113
163	Chestnut, Chinese	*Castanea mollissima*	Intermediate shade tolerance. Good survival and nut yield even on acid soils. Space about 20-40 ft apart for best crown development. Cover for wildlife. Nuts eaten by squirrels.	31,69,71,107
164	Redbud	*Cercis canadensis*	Legume. Tolerates shade. Grows on slightly acid and calcareous soils. Fruits eaten by birds and deer.	31,43,71,112,113
165	Dogwood, flowering	*Cornus florida*	Shade tolerant, slow-growing, long lived, and forms coppices freely. Grows best on well-drained soils. Seed eaten by wild turkeys.	54,69,107,112,113,116
166	Ash, white	*Fraxinus americana*	Shade intolerant. Deep and fibrous root system. Adapted to a wide range of soils.	31,43,54,69,71,107,113
167	Sweetgum	*Liquidamber styraciflua*	Shade intolerant. Grows on poorly drained soils but not well adapted to a soil pH below 5.0. Rapid-growing and long lived. Growth rate comparable to red and white pine in western Kentucky and southern Indiana.	31,54,69,71,107,113
168	Tulip tree	*Liriodendron tulipifera*	Rapid-growing when young, but not easily transplanted. Deep and spreading root system. Often forms thickets in rapidly gullying ravines. Fruit eaten by birds and deer.	31,54,69,71,112,113
169	Cucumber tree	*Magnolia acuminata*	Rapid-growing, short lived. Taproot rarely developed. Forms coppices freely after fire.	
170	Crabapple, American	*Malus* spp.	Shade intolerant. Adapted to dry, well-drained sites. Forms dense spiny thickets. Provides food, cover, and shelter for birds and deer.	5,27,54,69,107
171	Crabapple, American	*Malus coronaria*	Shade intolerant. Forms dense spiny thickets. Grows well on poorly drained soils.	
172	Sycamore	*Platanus occidentalis*	Shade intolerant. Pioneer specie in central United States. Tolerates wet soils and poorly drained depressions. Excellent for disposal sites. Grows on relatively flat areas. Good leaf litter and detritus producer.	31,54,69,71,107,112,113
173	Poplars, hybrids	*Populus* spp.	Grows rapidly and survives well in acid soils, but intolerant of grass competition.	108
174	Poplar, white	*Populus alba*	Shade intolerant. Grows well on dry soils.	52,54,73,113
175	Cottonwood, eastern	*Populus deltoides*	Shade intolerant. Rapid-growing but short lived. Shallow root system. Good soil stabilizer. Survives in infertile sands and stiff clays. Prefers well-drained moist areas. Plant in pure stands.	54,107,113
176	Poplars, hybrid	*Populus robusta*	Shade intolerant. Good survival at low soil pH. Grows rapidly but cannot withstand grass competition. Tree buds eaten by grouse. Marketable timber after about 20 years.	73,107

(Continued)

(Sheet 11 of 13)

Table E-10 (Continued)

No.	Common Name	Scientific Name	Comments	References
177	Oak, sawtooth	*Quercus acutissima*	Shade intolerant. Prefers favorable moisture and an initial soil pH >5.0. Plants from 4-6 years old may be heavily browsed by deer compared to other tree species.	31,69,108
178	Oak, white	*Quercus alba*	Shade intolerant. Taproot well developed. Slow-growing. Important food (acorns) for deer, squirrels, and rabbits.	31,54,69,71,107,113
179	Red oak, northern	*Quercus rubra*	Intermediate shade tolerance. Provides mast and cover. Plant on upper and lower slopes only. Good survival. Seedling growth is slow but accelerates after 4-6 years.	54,69,107,113
180	Locust, black	*Robinia pseudoacacia*	Shade intolerant. Legume. Can be direct seeded. Plant dominant. Stem clones in mixed plantings of other hardwoods. Forms good leaf litter and detritus.	5,27,31,54,69,73,82,107,112,116, 117
181	Sassafras	*Sassafras albidum*	Shade intolerant. Adapted to sands and droughty sites. Forms dense thickets. Forms coppices freely after cutting. Pioneer specie in old fields. Small tree. Fruit used for food by birds and animals.	31,54,69,113
182	American Holly	*Ilex opaca*	Adapted to a wide range of soil textures. Easy to transplant when young. Slow-growing and long lived. Berries are eaten by wild turkeys and deer.	31,54,116
183	Larch, Japanese	*Larix leptolepis*	Shade intolerant. Should be planted on noncompacted and nonleveled soils. Plant in bands or blocks. Provides good litter and detritus.	107
184	Magnolia, evergreen	*Magnolia grandiflora*	Easily transplanted. Grows to a large tree. Fruit (drupe) eaten by wild turkey and gray squirrels.	31,54
185	Spruce, white	*Picea glauca*	Shade intolerant. Has shallow, spreading root system. Heavy seed production occurs at intervals of 5-8 years. Provides nesting sites for birds; food for deer and squirrels.	69,82,107
186	Pine, Caribbean	*Pinus caribaea*	Rapid-growing. Shade intolerant. Wood is hardy, strong, and durable. Adapted to a wide range of soil textures.	31
187	Pine, shortleaf	*Pinus echinata*	Shade intolerant. Grows poorly on limestone soils. Will grow on all slopes and exposures. Least exacting of all southern pines. Young trees sprout freely after burning or cutting. Susceptible to southern pine beetle and little-leaf disease.	69,107,111,112,113
188	Pine, red	*Pinus resinosa*	Shade intolerant. Will grow on dry, acid soils overlying well-drained limestone and on poorer soils than white pine. Plant on all slopes.	69,107,116,117
189	Pine, pitch	*Pinus rigida*	Shade intolerant. Deep rooted. Deer prefer small seedlings. Plant in bands or blocks.	69,71,107,112
190	Pine, white	*Pinus strobus*	Shade intolerant. Will grow on loams and silty soils with either good or imperfect drainage, but does best on well-drained soils. Will grow on all slopes and exposures. Plant in bands or blocks.	54,69,71,112,116,117

(Continued)

(Sheet 12 of 13)

Table E-10 (Concluded)

No.	Common Name	Scientific Name	Comments	References
191	Pine, loblolly	*Pinus taeda*	Shade intolerant. Grows rapidly on flat, well-drained sites. Seedlings have a long taproot but older trees have a spreading root system. Susceptible to ice damage. Plant in bands or blocks.	31,107,111,113
192	Pine, Japanese black	*Pinus thunbergii*	Adapted to a wide range of soil textures. Very adaptable and hardy specie. Has excellent form at maturity. Grows rapidly under favorable climatic and soil conditions.	
193	Pine, Virginia	*Pinus virginiana*	Shade intolerant. Can be direct seeded. Slow-growing. Drought tolerant. Should be planted in bands of five rows or more or in pure block planting. Provides food and cover for wildlife.	69,82,107,111,112
194	Oak, live	*Quercus virginiana*	Prefers full sun. Small to large evergreen hardwood. Deep root system. Salt tolerant. Acorns produced on plants 12 in. tall. Produces stump sprouts.	31,54

(Sheet 13 of 13)

APPENDIX F: GUIDE TO SHORT-TERM MULCHES

APPENDIX F: GUIDE TO SHORT-TERM MULCHES

Tables F-1 and F-2 summarize mulch materials, their rates of application and uses, and the anchoring methods and materials required. These tables are designed for quick reference. More detailed discussions of mulch materials can be found in Section VI.

Table F-1

Guide to Short-Term Mulch Materials, Rates, and Uses

Mulch Material	Quality Standards	Application Per 1000 sq ft	Application Per Acre	Depth of Application	Advantages	Disadvantages	Remarks*
Sawdust, green or composted	Free from objectionable coarse materials	83-500 cu ft	--	1 in. - 7 in.	Protects surface Adds organic matter No weed seeds More fire resistant than straw Long lasting	Shavings and sawdust blow Nitrogen deficiency Packing may occur resulting in less aeration May float on running water	Most effective as a mulch around ornamentals, small fruits, and other nursery stock. Special application rates - fruit trees 5-7 in.; vegetables and flowers 2-3 in.; blackberries and raspberries 4-7 in.; strawberries 3 in. Good resistance to wind blowing. Requires 30-35 lb N/ton to prevent N deficiency while mulch is decaying. One cubic foot weighs 24 pounds.
Wood chips	Green or air dried. Free from objectionable coarse materials	500-900 lb	10-15 tons	2 in. - 7 in.	Easy to apply Chips resistant to wind movement	May prevent precipitation from reaching soil	Has about the same use and application as sawdust but requires less N/ton (10-12 lb). Resistant to wind blowing. Decomposes slowly
Wood excelsior	Green or air dried burred wood fibers 0.024 in. × 0.041 in. × 4 in.	90 lb (1 bale)	2 tons	--			Effective for erosion control. Tiedown needed on windy sites. Decomposes slowly. Packaged in 80- to 90-lb bales.
Wood fiber cellulose (partly digested wood fibers)	Usually dyed green. No growth organism inhibiting factors. Air dried 30 percent fibers 3.7 mm	25-30 lb	1000-1500 lb	--			When used for erosion control on critical areas double application rate. Apply with hydro-mulcher. No tiedown required. Packaged in 100-lb bags. Has not been very satisfactory for establishing seedings on arid sites.
Compost or manure	Well shredded, free from excessive coarse material	400-600 lb	8-10 tons	--	Can protect soil surface and adds nutrients, such as N, P, K, S	When used alone, it becomes wet, then dry, can lose much of N through volatilization of ammonia	Use a strawy manure when erosion control is needed. May create problems with weeds. Excellent moisture conserver. Resistant to wind blowing
Cornstalks or sorghum stover, shredded or chopped	Air dried, shredded into 8- to 12-in. lengths	150-300 lb	4-6 tons	--			Effective for erosion control, relatively slow to decompose. Excellent for mulch crop on fields. Has about the same value as a cover crop. Resistant to wind blowing

(Continued)

* All mulches will provide some degree of erosion control, moisture conservation, weed control, and reduction of soil crusting.

(Sheet 1 of 3)

Table F-1 (Continued)

Mulch Material	Quality Standards	Application Per 1000 sq ft	Application Per Acre	Depth of Application	Advantages	Disadvantages	Remarks
Grass hay or grain or straw	Air dried, free from undesirable seeds and coarse materials	75-100 lb 2-3 bales	1.5-2.5 tons 90-120 bales	Lightly covers 75 to 90 percent of surface	Generally most economical Usually satisfactory under many circumstances	Weed seeds usually present; even hay seeds may be considered a weed on a particular site Straw may "wick-out" moisture from soils in very dry conditions, thus resulting in poor germination and seedling establishment	Use straw where mulch effort to be maintained for more than 3 months. Subject to wind blowing unless kept moist or tied down. Most common and widely used mulching material. Good for erosion control in critical areas. Anchor mulch, especially on slopes by crimping, or using plastic meshes, jute, chemical tackifiers. Long stemmed best, especially for crimping. Uniform application important. Can be spread with modified farm manure spreader.
In situ mulches (cereal grains or summer annual crops like wheat, barley, or rye)					Produces quick cover to stabilize disturbed areas. Provides uniform mulch. More economical than artificially applied mulching materials		Fall crops killed with herbicides in spring before maturity, summer annuals killed by frost in fall. Interseed with permanent grasses and legumes species. Produces up to 2.5 tons/acre dry matter.

Mulch Material	Quality Standards	Unit Size	Unit and Weight	Area Covered Per Unit	Advantages	Disadvantages	Remarks
Mats and Netting					Especially useful on steep slopes Nets good in high wind areas	Expensive: 4-5 times more than tacked straw High labor input for anchoring Not effective on rough surfaces or rocky areas Erosion from beneath may be a problem	Used only on limited critical areas because of cost
Twisted kraft paper yarn	Plain weave, warp 7 per inch, filling 4 per inch selvage edge with polyproplyene filament	45 in. × 250 yd	Roll 100 lb	312-1/2 sq yd			Used to hold seed and aid in germination without mulch. Tie down according to manufacturing specifications. Not effective in seeding establishment on arid sites. Lasts about one year.

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AD-A157 649 ENVIRONMENTAL IMPACT RESEARCH PROGRAM RESTORATION OF PROBLEM SOIL MATERIA..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. C R LEE ET AL. 6/6

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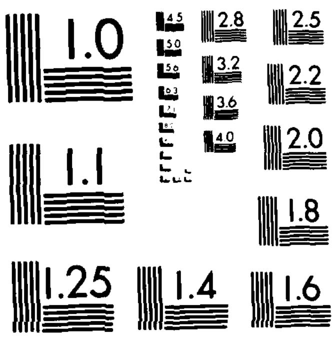

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Table F-1 (Concluded)

Mulch Material	Quality Standards	Unit Size	Unit and Weight	Area Covered Per Unit	Advantages	Disadvantages	Remarks
Twisted kraft paper yarn	Fungicide treated warp 1.1 pairs/in., filling 2.5/in.	45 in. × 250 yd	Roll 80 lb	312-1/2 sq yd			Use over bare soil or sod to prevent erosion and hold seed. Good for waterways and critical ditch bottoms. Tie down with staples as per manufacturing specifications and on critical areas. Lasts about one year.
Jute, twisted yarn	Undyed, unbleached plain weave. Warp 78 ends/yd 41 ends/yd	45 in. × 50 yd or 48 in. × 75 yd	Roll 60 lb 90 lb	60 sq yd 100 sq yd			Use without additional mulch. Tie down as per manufacturing specifications. Effective for erosion control in waterways and ditches. Lasts about one year.
Excelsior wood fiber mats	Interlocking web of excelsior fibers w/mulch net backing on one side only.	36 in. × 30 yd	Roll --	16-1/2 sq yd			Use without additional mulch. Tie down as per manufacturing specifications. Good for establishing seedings on critical areas.
Plastic	2-4 mils	Variable up to 50 ft wide	--	--	Excellent vapor barrier Good weed control Light colored, perforated, found effective in New Mexico: soil temperature in summer 18°F lower than in soil with no mulch	Labor intensive High cost	Use black for weed control, use white for seeding establishment without organic mulch. Release plastic after seeding is established. Information on temperature effect varies. The materials allow air and water interchange but prevent evaporation of soil moisture. Usually must be renewed each season. Some users place a 1-in. layer of sand underneath to prevent it from tearing when stepped upon. Must be punctured with frequent small holes for penetration of air and water and weighted down around edges.

(Sheet 3 of 3)

Table F-2

Mulch Anchoring Guide

Anchoring Method or Material	Kind of Mulch to be Anchored	How to Apply
Manual		
Peg and twine	Hay or straw, pine straw, corn stalks	After mulching, divide areas into blocks approx. 1 sq yd in size. Drive 4-6 pegs per block to within 2 to 3 in. of soil surface. Secure mulch to surface by stretching twine between pegs in criss-cross pattern on each block. Secure twine around each peg with two or more turns. Drive pegs flush with soil where mowing and maintenance are planned
Mulch netting	Hay or straw, shredded sugar cane, pine straw, compost, wood shavings, tanbark, corn stalks	Staple with lightweight paper, jute, wood fiber, or plastic nettings to soil surface according to manufacturer's recommendations
Soil and stones	Plastic	Plow a single furrow along edge of area to be covered with plastic, fold about 6 in. of plastic into the furrow and plow furrow slice back over plastic. Use stones to hold plastic down in other places as needed
Silt	Hay or straw, corn stalks	Cut mulch into soil surface with square-edge spade. Make cuts in contour rows spaced 18 in. apart
Mechanical		
Asphalt spray (emulsion)	Compost, wood chips, wood shavings, hay or straw	Apply with suitable spray equipment using the following rates: asphalt emulsion 0.04 gal/sq yd; liquid asphalt (*rapid*, *medium*, or slow setting) 0.10 gal/sq yd
Wood cellulose fiber	Hay or straw	Apply with hydroseeder immediately after mulching. Use 750 lb wood fiber per acre

(Continued)

Table F-2 (Concluded)

Anchoring Method or Material	Kind of Mulch to be Anchored	How to Apply
Pick chain	Hay or straw, manure compost, pine straw	Use on slopes steeper than 3:1. Pull across slopes with suitable power equipment
Mulch anchoring tool or disk (smooth or notched)	Hay or straw, manure, pine straw	Apply mulch and pull a mulch anchoring tool over mulch. When a disk (smooth) is used, set in straight position and pull across slope with suitable power equipment. Mulch material should be "tucked" into soil surface about 3 in.
Chemical	Hay or straw	Apply Terra Tack II (45 lb) or Aerospray 70 (60 gal/acre) according to manufacturer's instructions. Avoid application during rain. A 24-hr curing period required and soil temperature higher than 45°F.
Sheepsfoot roller or packer	Hay, straw, manure, corn stalks	Pull sheepsfoot roller over the areas after mulch is applied. Can be operated up and down the slope

APPENDIX G: SOURCES OF INFORMATION

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APPENDIX G: SOURCES OF INFORMATION*

* This appendix lists various sources of further information. Upto-date information and restoration plans should be discussed with appropriate local expertise prior to implementation of restoration plans.

Listing of Information Sources

Federal Legislation

River and Harbor Acts
PL 92-500 (Clean Water Act)
Wild and Scenic Rivers Bill

National Environmental Policy Act
Transportation Acts
Wilderness Bill
Endangered Species Act

National Policies and Related Actions

P&S (Water Resources Council)
Exec. Order 11296

National Goals
Energy Conservation Requirements

Agency Policy and Related Actions Within the Corps

ER's, EC's, & Multiple Letters
Environmental Inventories
Previous Study Reports
Institute of Water Resources Reports

Agency Sources Outside the Corps

- Bureau of Reclamation
- Bureau Land Management
- Office of Surface Mining
- US Environmental Protection Agency
- WRC Conservation Service
- Soil Conservation Service
  - Plant Materials Centers (see Table G-1)
  - Plant Materials Specialists (see Table G-2)
  - Technical Service Centers
  - Soil Survey
- US Forest Service
  - National Forests
  - State and Private Forests
- Forest and Range Experiment Stations

State Government Sources

Governor's Office
Legislature

- Existing Legislation
- Pending Legislation

Policies and Administrative Agencies

- Planning
- Fish and Wildlife
- Health
- Water Supply
- Water Quality (Sediment Controls)
- Recreation
- Land Use
- Transportation
- Agriculture (Land Grant Univ. and Exp. Station)
- Commerce
- Natural Resources

Local Sources

- Counties
- Cities
  - Land Use Plans
  - Transportation Plans
  - Recreation Plans
  - Public Service Plans
  - Education

- Regional Sources
  - Councils of Government
  - Interstate Agencies (e.g., Appalachian Regional Council/Old West Regional Council)
  - River Basin Commissions

- Scientific/Professional/Business Organizations
  - Universities
  - Clubs
  - Fraternal Orders
  - Chambers of Commerce
  - Professional Societies

- Private Industry

- News Media

- Citizens Groups
  - Environmental
  - Civic
  - PTA's
  - Consumer Groups
  - Political Clubs

Social Action
Religious
Home Owners Associations

Additional sources of information are given in Table G-3. Some sources of seed and plants are given in Table G-4.

Table G-1

Plant Materials Centers, Soil Conservation Service, and Cooperating Agencies as of March 1984

ALASKA, Star Route B, Box 744, Palmer 99645
ARIZONA, 3241 Romero Road, Tucson 85705
CALIFORNIA, 21001 N. Eliot, Lockeford 95237
FLORIDA, 14119 Broad Street, Brooksville 33512
GEORGIA, Route 3, Patton Drive, Americus 31709
HAWAII, P.O. Box 236, Hoolehua, Molokia 96729
IDAHO, P.O. Box AA, Aberdeen 83210
KANSAS, Route 2, P.O. Box 314, Manhattan 66502
KENTUCKY, Plant Materials Centers, Quicksand 41363
MARYLAND, Building 509, Agricultural Research Center, Beltsville 20705
MICHIGAN, Route 7, 7424 Stoll Road, East Lansing 48824
MISSISSIPPI, Route 3, Box 215A, Coffeeville 38922
MISSOURI, Route 1, Box 9, Elsberry 63343
MONTANA, Route 1, Box 81, Bridger 59014
NEW JERSEY, P.O. Box 236-A, RD-1, Cape May Court 08210
NEW MEXICO, 1036 Miller Street, Los Lunas 87031
NEW YORK, Box 36A, RD1, Route 352, Corning 14830
NORTH DAKOTA, P.O. Box 1458, Bismarck 58501
OREGON, 3420 Northeast Granger Avenue, Corvallis 97330
TEXAS, Route 1, Box 155, Knox City 75929
WASHINGTON, Johnson Hall, Washington State University, Pullman 99163

Source: Updated from US Environmental Protection Agency (1975, Jul). "Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities," Office of Water Planning and Standards, EPA-440/975006, Washington, D.C.

Table G-2

Soil Conservation Service, Plant Materials

Specialists as of March 1984

National Plant Materials Specialist

Robert S. MacLauchlan
Soil Conservation Service
PO Box 2809
Washington, DC 20013
FTS: 4475667

National Technical Center (NTC) Plant Materials Specialists

Northeast NTC
W. Curtis Sharp
1974 Sprout Road
Broomall, Pennsylvania 19008
FTS: 489-3223

South NTC
Wayne Everett
PO Box 6567
Fort Worth, Texas 76115
COMM: (215)461-3223FTS: 334-5282

Midwest NTC
Kenneth Blan
USDA-SCS
Federal Building
US Courthouse, Room 378
Lincoln, Nebraska 68505
FTS: 541-5355

West NTC
Robert D. Slayback
2828 Chiles Road
PO Box 1019
Davis, California 95616
COMM: (916)449-2857

Field Plant Materials Specialists

Alaska
Calvin Miller
2221 E. Northern Lights Blvd.
Suite 1292828
Anchorage, Alaska 99508
COMM: (907)276-4246

California
Robert D. Slayback
Chiles Road
PO Box 1019
Davis, California 95616
COMM: (916)758-2200, ext. 275

Arizona
Jacob C. Garrison
3008 Federal Building
231 N. First Avenue
Phoenix, Arizona 85025
FTS: 261-6711, ext. 43
COMM: (602)261-6711, ext. 43

Colorado
Wendell Hassell
Diamond Hill Complex
Bldg A 3rd Floor
2490 W. 26th Ave.
Denver, Colorado 80211
FTS: 327-5651
COMM: (303)837-5651

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(Sheet 1 of 6)

Table G-2 (Continued)

Florida
Bob Glennon
14119 Broad Street
Brookville, Florida 33512
FTS: (904)796-9600

Georgia
Edward D. Surrency
Federal Building
335 E. Hancock Avenue
Athens, Georgia 30601
FTS: 250-2114, or 2115

Hawaii
Robert J. Joy
Box 74
Hoolehua, Hawaii 96729
FTS: 556-0220
COMM: (808)577-6378

Idaho
George James
304 North 8th Street
Room 345
Boise, Idaho 83702
FTS: 554-1068
COMM: (208)334-1068

Kansas
Jack W. Walstrom
768 S. Broadway
Salina, Kansas 67401
COMM: (913)823-4551

Kentucky
Donald S. Henry
333 Waller Avenue, Room 305
Lexington, Kentucky 40504
FTS: 355-2738
COMM: (606)233-2738

Michigan
Dorian A. Carroll
1405 South Harrison Road
East Lansing, Michigan 48823
FTS: 374-6677
COMM: (517)337-6701

Montana
Larry Holzworth
Federal Building, Room 443
10 E. Babcock
Bozeman, Montana 59715
FTS: 585-4332
COMM: (406)587-5271, ext. 4332

New Jersey
Frank Webb
1370 Hamilton Street
Somerset, New Jersey 08873
FTS: 342-5341
COMM: (201)246-1206

New Mexico
Bill Fuller
517 Gold Avenue, S. W.
PO Box 2007
Albuquerque, New Mexico 87103
FTS: 474-1843

New York
Jack A. Dickerson
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(Continued)

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Lime Requirement

4. The buffering capacity or exchangeable + pH induced acidity makes up the bulk of the total acidity of most soils with the exception of acid sulfate soils. The lime requirement, which is the amount of a liming material (usually expressed as pounds per acre to a 6-in. depth) required to change the soil pH to some desired value, is a measure of the buffering capacity of a soil.

5. Originally, the lime requirement of soils was estimated from lime-buffer curves which were determined from either limestone-soil incubation procedures or soil-lime equilibrium reactions.

6. In the limestone-soil incubation procedure, varying quantities of calcium carbonate are added to a definite weight of soil placed in a series of open containers. After thoroughly mixing the soil and calcium carbonate, the mixture is incubated under moist, aerobic conditions for a definite period (usually several months). At the end of this period, the pH of the different calcium carbonate-soil mixtures is determined and the lime-buffer curve is obtained by plotting soil pH versus pounds of calcium carbonate per acre.

7. For the soil-lime equilibrium reactions, a definite weight of air-dried soil (usually 10 g) is weighed into a series of Erlemeyer flasks containing about 30 ml of distilled water. A varying increment of a standardized solution of $Ca(OH)_2$ is pipetted into the soil solution and the flask stoppered and shaken mechanically until equilibrium is obtained (from 24 to 48 hr). The pH of each mixture is determined and the lime-buffer curve is obtained, as with the limestone-soil incubation procedure, by plotting the pH of the soil versus millilitres of $Ca(OH)_2$ (converted to pounds of calcium carbonate per acre).

8. Both procedures are time-consuming and are not adaptable to estimating the lime requirements of a large number of different soils daily, as required in a soil testing laboratory. However, they are still used as the standard for comparing the effectiveness of any new buffer as a predictor of the lime requirement and for comparing existing buffer systems for other soil groups.

9. Mehlich (1941, 1942) determined the pH-percent base saturation curves (buffer curves) for various clay mineral and organic colloids and showed that the curves were decidedly different from each other. By knowing

APPENDIX H: ACID SULFATE SOILS--SELECTED METHODS FOR ESTIMATING LIME REQUIREMENTS BASED ON THE BUFFERING CAPACITY AND THE ACID-FORMING POTENTIAL OF THE OXIDIZABLE SULFUR CONTENT

1. Acid sulfate soils may be defined as all soils containing materials which during weathering have produced, are producing, or will produce sufficient acidity as H_2SO_4 to either materially inhibit or prevent plant growth. Prior to oxidation, most of these acid-forming materials are in the form of sulfides with pyrite being the dominant compound. Bloomfield and Coulter (1973) and van Breeman (1973) have written an extensive review on the genesis and management of these soils.

2. The potential acidity (lime requirement) of all soils is estimated from the soil pH and buffering capacity. For acid sulfate soils, a third factor has to be estimated. This is the oxidizable sulfur content of the soil (H_2SO_4 producing capacity).

Soil pH

3. pH is a measure of the active acidity of the soil. While pH comprises only a very small percentage of the total soil acidity, it provides an estimate of the quantities of essential and/or toxic elements present that may be available to plants--the solubility of many elements and compounds being controlled by pH. At soil pH values below 5.2, toxic quantities of soluble aluminum and/or manganese may be in solution. These low pH values indicate also a low percentage of base saturation and a deficiency of the available bases (calcium, magnesium, and potassium) necessary for optimum crop growth. Depending upon the soil colloidal system, soils with a pH value in the 5.5 to 6.5 range contain adequate bases for crop growth with the percent base saturation increasing with soil pH. At pH values of 6.5 and above, deficiencies of manganese, zinc, copper, and iron may exist due to the formation of relatively insoluble compounds of these elements. In some systems for estimating the lime requirement, soil pH is required in addition to the buffer pH value.

APPENDIX H: ACID SULFATE SOILS

APPENDIX H: ACID SULFATE SOILS--SELECTED METHODS FOR ESTIMATING LIME REQUIREMENTS BASED ON THE BUFFERING CAPACITY AND THE ACID-FORMING POTENTIAL OF THE OXIDIZABLE SULFUR CONTENT

Table G-4 (Concluded)

Harpool Seed, Inc. Drawer B Denton, Texas 76201 (817)387-0541	Star Seed & Grain Corp. 607 Lookout Drive San Antonio, Texas 78204 (512)227-5344
Flieller Feed and Seed 1303 3rd Floresville, Texas 78114 (512)393-2836	Empire Seed Co. 109 E. Ave. A Temple, Texas 76501 (817)778-7109
George Warner Seed, Inc. Box 1448 Hereford, Texas 79045	Bunch Seed Store 321 Texas Texarkana, Texas 75501 (214)794-3771
Miller Seed Co. Box 886 Hereford, Texas 79045 (806)364-5251	East Texas Seed Co. PO Box 1132 Tyler, Texas 75701 (214)597-6637
G. E. Pogue Seed Box 126 Kenedy, Texas 78119 (512)583-3456	Conlee Seed Co. Box 267, 481 Texas Central Waco, Texas 76710 (817)772-5680
Young Seed and Grain Co. R. C. 626-27th Street Lubbock, Texas 79404 (806)744-1408	Jacklin Seed Co. E. 8803 Sprague Avenue Post Falls, Washington 99213
Baumert Seed Co. Rt. 3, Box 192 Muleshoe, Texas 79347 (806)272-4787	Game Food Nurseries PO Box V Omro, Wisconsin 54963 (414)685-2929

(Sheet 4 of 4)

Table G-4 (Continued)

Eisenman Seed Co. Fairfield, Montana 59436 (406)467-2521	Williamette Seed and Grain Seed Co. PO Box 25 Shedd, Oregon 97377
Horizon Seed Co. PO Box 81823 Lincoln, Nebraska 68501	Ernst Crownvetch Farms RD 5 Meadville, Pennsylvania 16335 (814)425-7276
Herbst Bros., Seedsmen, Inc. 1000 N. Main Brewster, New York 10509 (914)279-9616	Gifford Feed and Seed Store PO Box 157 Estill, South Carolina 29918 (803)625-3033
Stanford Seed Co. 560 Fulton St. Buffalo, New York 14240	Tennessee Farmers Cooperative PO Box 3003 200 Waldron Rd. La Vergne, Tennessee 37086 (615)793-8011
McNair Seed Co. PO Box 706 Laurinburg, North Carolina 28352	Russell-Heckle Seed Co. 29 Linden Ave. Memphis, Tennessee 38103 (901)725-5255
Ross Seed and Grain Co. Box 679 Chickasha, Oklahoma 73018	Quality Seed Inc. Box 666 Jordan Highway Union City, Tennessee 38261 (901)885-9782
Johnston Seed Co. Box 1392 Enid, Oklahoma 73701 (405)233-5800	Sharp Bros. Seed 4378 Canyon Drive Amarillo, Texas 79109 (806)352-2781
Tom Munger Seed Co. 312 E. Pine Enid, Oklahoma 73701 (405)238-7812	Eastern Seed Co. Corpus Christi, Texas 78403 (512)883-1521
North Coast Seed Co. PO Box 12185 Portland, Oregon 97212 (503)227-5310	Nicholas, Robert Seed Co. 4803 Allendale Dallas, Texas 75202 (214)358-1006

(Continued)

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(404)358-1454

Hardeman Seed Co.
PO Box 387
Louisville, Georgia 30434
(912)625-3056

Farmers Mutual Exchange
276 Lower Boundary
Macon, Georgia 31206
(912)745-6551

Pennington Grain and Seed
PO Box 290
Madison, Georgia 30650
(404)342-1234

Economy Feed and Seed
646 W. Bay Street
Savannah, Georgia 31402
(912)237-9862

Fukuda Seed Store
528 Kaaahi Street
Honolulu, Hawaii 96817
841-6719

Honolulu Seed Co.
935 C Dillingham Blvd.
Honolulu, Hawaii 96817

Northplan Seed Producers
Box 9107
Moscow, Idaho 83843
(208)832-8040

Union Seed Co.
Box 339
Nampa, Idaho 83651
(208)466-3568

Globe Seed and Feed Co.
PO Box 445
224 4th Ave. S.
Twin Falls, Idaho 83301
733-1373

Sharp Brothers Seed Co.
PO Box 140
Healy, Kansas 67850

Cayce-Yost Seed Co.
Box 629
Hopkinsville, Kentucky 42240
(606)885-6181

Caudill Seed Co.
1201 Stony Avenue
Louisville, Kentucky 40206
(502)583-4402

Wm. G. Scarlett and Co.
729 E. Pratt St.
Baltimore, Maryland 21202

Wax Seed Company
Amory, Mississippi 38821
(601)256-3511

Sawan Seed Company
Columbus, Mississippi 39701
(601)327-7333

Montana Seeds, Inc.
Rt. 3
Conrad, Montana 59425
(406)278-5547

(Continued)

Table G-4

Sources of Seed and Plants

Norala Seed Co.
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Birmingham, Alabama 35201

Mid-State Farmers Cooperative
PO Box 413
Columbiana, Alabama 38051

Montgomery Seed and Supply Co., Inc.
PO Box 349
Montgomery, Alabama 36102
(205)699-7082

Bomar Feed and Seed Co.
Tuscaloosa, Alabama 36104
(205)758-3671

Northrup, King and Co.
PO Box 21064
Phoenix, Arizona 85036

Valley Seed Co.
PO Box 1110
Phoenix, Arizona 85001

Arizona Range Grass Seed Co.
Rt. 1, Box 850
Willcox, Arizona 85643
(602)384-2451

Kaufman Seed Co.
Box 390
Ashdown, Arkansas

Kamprath Seed Co.
PO Box 2162
Bakersfield, California 93303
(805)831-3456

Environmental Seed Producers, Inc.
PO Box 5904
El Monte, California 91734
(213)442-3330

Pecoff Bros. Nursery and Seed
Rt. 5, Box 215R
Escondido, California 92025
(619)744-3120

Northrup-King & Co.
2850 So. Highway 99
Fresno, California
(209)237-4731

Stover Seed Co.
1415 E. 6th Street
Los Angeles, California 90013
(213)626-9668

Ramsey Seed, Inc.
PO Box 352
Manteca, California 95336

Ferry-Morse Seed Co.
Box 7274
Mountain View, California 94039
(415)967-6973

S&S Seeds
910 Alphonse
Santa Barbara, California 93103
(805)967-6927
(805)965-5243

Applewood Seed Co.
5380 Vivian Street
Arvata, Colorado 80002
(303)431-6283

Fulton-Cole Seed Co.
PO Box 98
Alturas, Florida 33820
(813)537-1331

(Continued)

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Table G-3 (Concluded)

Information Aid	Where Obtained	Information Available
Vegetative maps	US Department of Agriculture, Independence Ave. between 12th and 14th Sts., S.W., Washington, D.C. US Forest Service State forestry division State agriculture division Local universities Infrared and other aerial photographs	1. Types and extent of vegetative cover 2. Density of cover
Geologic maps and reports	Universities US Geological Survey State geological survey	1. Kinds of strata 2. Location of geologic hazards a. Faults b. High-water tables 3. Strikes and dips of various strata 4. Geologic trends in the area 5. Topographic features and their relationship to the geology

Table G-3

Published Information Aids*

Information Aid	Where Obtained	Information Available
Aerial photographs to LANDSAT imagery	East of the Mississippi River: US Geological Survey, Distribution Center, 1200 South Eads St., Arlington, Va. 22202 West of the Mississippi River: US Geological Survey, Federal Center Bldg. 41, Denver, Colo. 80225 Local air services US Soil Conservation Service (SCS) US Forest Service Agricultural Stabilization and Conservation Service NASA EROS Data Center, Sioux Falls, S. Dak.	1. Drainage networks 2. Land forms 3. Extent of alluvium, and other 4. Vegetative patterns (infrared) 5. Fracturing and joint-patterns 6. Slope gradients 7. Location of mass movements 8. Land cover characteristics
Topographic maps	Same as aerial photographs	1. Benchmarks 2. Slope gradients 3. Location of roads, buildings, and nearest towns 4. Drainage basins 5. Relief 6. Stream systems
Soil surveys	US Soil Conservation Service, Independence Ave. between 12th and 14th Sts., S.W., Washington, D.C. Local Soil Conservation Service office	1. Types of soils 2. Extent of various soils 3. Engineering properties of soils 4. Land use potentials for various soils 5. Erodibility of soils 6. Aerial photographs 7. General textural characteristics of the soils

(Continued)

* US Environmental Protection Agency (1976).

Table G-2 (Concluded)

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Table G-2 (Continued)

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Soil Conservationist
Bill Fry

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the cation exchange capacity of the soil and the dominant type of soil colloid, one could calculate from the soil pH and the appropriate pH-base saturation curve, the approximate quantity of limestone required to raise soil pH to any desired pH value.

10. It had been noted that the soil titration curves with $Ca(OH)_2$ showed a near linear relationship between changes in soil pH and millilitres of $Ca(OH)_2$ added for most soils in the pH range between 5.0 and 7.0. Woodruff (1948) developed and calibrated for Missouri soils one of the first quick procedures for estimating directly the lime requirement (buffer capacity) of a soil from the drop in pH of a strongly buffered solution (pH 7.0) when mixed with an acid soil at a specified soil-solution ratio. The pH of the mixture, following the equilibrium reaction between the acid soil and the buffer solution, is less than 7.0. The drop in pH is related directly to the amount of exchangeable acidity (buffering capacity or lime requirement) and when calibrated with lime-buffer curves can be converted directly into pounds of limestone per acre required to raise soil pH to a desired value (usually 6.5).

11. The Woodruff buffer procedure for estimating the lime requirement of soils was quickly accepted. Over the years, researchers in Ohio found that the Woodruff buffer underestimated the lime requirements of soils containing large amounts of exchangeable aluminum when compared with limestone- soil incubation studies. Shoemaker, McLean, and Pratt (1961) developed a new buffer that gave more accurate estimates of lime requirement for soils containing large amounts of exchangeable aluminum and, according to them, was equally effective for a wide range of soils. The method was designed to estimate the quantity of lime required to raise soil pH to 6.5 (became known as the SMP buffer).

12. About the same time Adams and Evans (1962) developed a weaker buffer than Woodruff's designed for the red-yellow Podzolic (Ultisols) soils (primarily 1:1 clay minerals mixed with hydrated oxides of iron and aluminum) which have a low cation exchange capacity. In these soils, which have a low lime requirement and where overliming reduces crop yields markedly, the Woodruff buffer frequently overestimated the lime requirement of the soil. This was due to the strong buffer (1000 lb of lime per acre for each 0.1 pH depression below 7.0) and the condensed pH scale common on pH meters of the time.

13. Both the Adams and Evans (1962) and Shoemaker, McLean, and Pratt (1961) methods use a table in which both the soil pH (1:1 ratio with water)

and the buffer pH are required to estimate the actual lime requirement in pounds of limestone per acre. The Adams and Evans (1962) calibration is based on the relationship between soil pH and percent base saturation while the calibration table for Shoemaker, McLean, and Pratt (1961) is based on the relationship between soil pH and exchangeable acidity.

14. Yuan (1974, 1976) was the first to point out that all of the buffer systems then in use were using an average slope for the line that measures the change in buffer pH with lime requirement. These had been derived by averaging the values from all the soils of a particular region. Therefore, it was an average lime requirement value and nonspecific for any particular soil.

15. Yuan developed a weaker buffer than that of Adams and Evans (1962). It was designed especially for the poorly buffered sandy soils of Florida and the Coastal Plains of the southeastern and gulf states. By using a double buffer procedure (two samples of each soil equilibrated with the buffer which had been buffered at pH 7 and pH 6, respectively), the calculated slope change was specific for each soil. This was based on the observation that the slope of the line indicating changes in soil pH from lime incubation procedures is more or less linear from pH 5.0 to 7.0.

16. In Yuan's procedure, two 5-g samples of soil are shaken for 1 hr with 50 ml of buffer solution. One sample is shaken with the pH 7.0 buffer and the other with the pH 6.0 buffer. The pH's of the two solutions are measured on a pH meter that has an expanded scale.

17. To illustrate the calculations suppose:

Soil pH with pH 7.00 buffer = 6.68 (h_1) Soil pH with pH 6.00 buffer = 5.83 (h_2)

$$@ = \frac{d_1 - d_2}{h_1 - h_1} \quad \text{where} \quad d_1 = 7.00 - h_1 \quad \text{and} \quad d_2 = 6.00 - h_2$$

$$@ = \frac{(7.00 - 6.68) - (6.00 - 5.83)}{6.68 - 5.83} = \frac{0.32 - 0.17}{0.85} = \frac{0.15}{0.85} = 0.177$$

me acidity per 5 g soil = d + @(h − h_1)

pH 7.00 = 0.32 + 0.177(7.00 − 6.68) = 0.377

pH 6.00 = 0.17 + 0.177(6.00 − 5.83) = 0.200

me acidity per 5 g soil × 10 = tons of calcium carbonate per acre

$0.377 \times 10 = 3.77$ tons of calcium carbonate to raise soil pH to 7.00

$0.200 \times 10 = 2.00$ tons of calcium carbonate to raise soil pH to 6.00

18. McLean, Trierweiler, and Eckert (1977) adapted Yuan's (1974, 1976) double buffer procedure to the SMP buffer and tested it on a wide variety of soils. Later, McLean et al. (1978) modified it for quick test procedures and also outlined a quicker lime titration procedure for estimating the amount of lime required to raise soil pH to 6.5 which compared well with lime-soil incubations over an extended period.

19. The method consists of titrating 10 g of soil suspended in 30 ml of distilled water with a 0.025 N $Ca(OH)_2$ solution to pH 7.2. The closed flask is shaken mechanically for 24 hr and again titrated to pH 7.2 with the 0.025 N $Ca(OH)_2$ solution. The procedure is repeated until the soil pH remains at 7.2 for 24 hr. From the total millilitres of $Ca(OH)_2$ used, the lime requirement is calculated in tons of calcium carbonate per acre.

20. Mehlich (1976) developed a new buffer designed to estimate the unbuffered salt-exchangeable acidity (Al^{3+} and H^+) in Ultisols, Histosols, and other mineral soils with relatively low cation exchange capacities. Numerous fertility studies on these type soils had demonstrated that optimum plant yields were associated with the neutralization of this fraction of soil acidity, provided adequate calcium and magnesium were available, rather than liming the soil to a definite pH.

21. There are a large number of papers in the literature in which several buffer procedures are compared to each other and to the accepted standard (limestone-soil incubations). Mehlich, Bowling, and Hatfield (1976) found that the SMP buffer (Shoemaker, McLean, and Pratt 1961) underestimated the lime requirement of soils with a low cation exchange capacity but was the most reliable when the lime requirement exceeded 2 tons/acre. Conversely, Tran and van Lierop (1981) found that the buffers of Adams and Evans (1962) and Mehlich (1976) had the lowest correlations with the limestone-soil incubation standard procedure on Canadian soils. They thought that the low correlation with the Adams and Evans (1962) buffer procedure was due to the solution being buffered at pH 8.0. They found that much higher correlations were obtained with the Adams and Evans (1962) buffer if a 1:4 buffer-water ratio was used instead of the 1:1 buffer-water ratio listed in the procedure. The South Carolina Soil Testing Laboratory has been using a similar modification since around 1970.

22. McLean (1973, 1978) and Mehlich, Bowling, and Hatfield (1976) discuss the principles behind buffer methods for estimating the lime requirements of acid soils. In addition to providing an understanding of fundamentals, their papers should help one to decide on the method(s) best suited for a particular situation.

23. In summary, the double-buffer procedure, using SMP, Yuan's, or some other buffer, should be the preferred procedure for estimating the buffering capacity of acid sulfate soils. If the lime requirement at pH 7.0 and pH 6.0 is plotted on a graph with pH on the y-axis and tons of calcium carbonate on the x-axis, by extrapolation of the straight line joining the two points, the quantity of lime required to raise the soil pH to any desired pH between 5.0 and 7.0 can be determined directly from the graph. A soil pH in the range of 5.0 to 5.2 may be all that is needed to establish and maintain an adequate plant cover.

Oxidation of Sulfides

24. Under moist, aerated conditions, the iron sulfides in soils oxidize rapidly to ferrous iron and sulfuric acid (Bloomfield and Coulter 1973, Singer and Stumm 1970). Although there is some disagreement as to the order, speed, and source (chemical or biological) for each reaction, the general consensus is that the oxidation of pyrite is brought about by one or more of the following reactions:

1. $2FeS_2 + 2H_2O + 7O_2 \longrightarrow 2FeSO_4 + 2H_2SO_4$ Chemical
2. $4FeSO_4 + O_2 + 2H_2SO_4 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$ Biological *T. ferrooxidans*
3. $FeS_2 + Fe_2(SO_4)_3 \longrightarrow 3FeSO_4 + 2S$ Chemical
4. $2S + 6Fe_2(SO_4)_3 + 8H_2O \longrightarrow 12\ FeSO_4 + 8H_2SO_4$ Chemical
5. $FeS_2 + 7Fe_2(SO_4)_3 + 8\ H_2O \longrightarrow 15FeSO_4 + 8H_2SO_4$ Combines Reactions 3 and 4
6. $2S + O_2 + 2H_2O \longrightarrow 2H_2SO_4$ Biological *T. thiooxidans*

25. Reaction 1 is a chemical reaction and is starte' either by the disassociation of FeS_2 or by oxidation with oxygen.

26. Reaction 2 is primarily biological. In a sterile, moist, aerated medium without ferric iron, reaction 2 proceeds very slowly (only about 50 percent of the Fe^{2+} oxidized to Fe^{3+} after 1000 days) (Singer and Stumm

1970). However, in the presence of the bacteria *Thiobacillus ferrooxidans*, reaction 2 takes place rapidly.

27. When Fe^{3+} is available, either in the presence or absence of oxygen, reactions 3 and 4 take place rapidly at room temperature. Reaction 5 merely combines 3 and 4 so as to eliminate intermediate products. Also the bacteria, *Thiobacillus thiooxidans* will oxidize elemental sulfur to H_2SO_4 according to reaction 6.

28. In the overall reactions, microorganisms are primarily responsible for oxidizing Fe^{2+} to Fe^{3+}. The Fe^{3+} is then chemically reduced by pyrite, producing acidity and additional Fe^{2+} which in turn is oxidized to Fe^{3+} by the microorganisms. Under moist, aerated conditions, the reactions are self-catalytic.

29. The rate of oxidation of iron sulfides could be decreased by controlling the levels of *T. ferrooxidans* or soluble Fe^{3+} in the soil. Bactericides have been used to reduce microbial activity and both lime and organic matter decrease the levels of available ferric iron (Singer and Stumm 1970). Organic matter is thought to complex Fe^{3+} and also reduce it to Fe^{2+} while lime, by raising soil pH, causes Fe^{3+} to precipitate as $Fe(OH)_3$.

Methods of Analysis

Sample collection and preparation

30. Place the freshly collected sample(s) in air-tight containers (plastic bags are permeable to oxygen) for transfer to the laboratory. Freeze-dry the sample, grind to a fine powder, and store in an air-tight container.

Qualitative tests for acid sulfate soils

31. Water-soluble and exchangeable sulfates: Add 20 ml of extracting solution (0.1 M $Ca(H_2PO_4)_2$, 0.5 N ammonium acetate in 0.25 N acetic acid or any recommended extracting solution for SO_4-S) to 5 g of soil along with approximately 200 mg of charcoal (SO_4-free). Shake the mixture for 10 min on a mechanical shaker, and filter immediately through Whatman #2 filter paper or equivalent. Determine the concentration of SO_4-S by any of the procedures listed under sulfate analysis.

32. Sulfide sulfur (method a) (Ford and Calvert 1970, Calvert and Ford 1973): Place 2 g of soil in a 100-ml digestion flask, add 15 ml of 30 percent H_2O_2, and apply heat slowly until the reaction starts. After the reaction is

complete (additional increments of H_2O_2 do not cause a reaction), determine the pH of the mixture. Filter the suspension, evaporate the filtrate to around 10 ml volume, add 1 ml of a 25 percent barium chloride solution, mix thoroughly, and estimate the quantity of sulfide present by the density of the $BaSO_4$ precipitate.

33. To be a potential acid sulfate soil, both the pH of the H_2O_2 treated soil suspension must be below 3.0 and the filtrate must contain a high level of SO_4-S (even after subtracting the level of water-soluble and exchangeable SO_4-S).

34. Sulfide sulfur (method b) (Feigl 1946): Dissolve 10 g of sodium azide and 10 g of potassium iodide in 30 ml of water. Add a small crystal of iodine. Place a small sample of the suspected soil in a centrifuge tube and add enough of the sodium azide solution to cover the soil. An effervescence of fine bubbles of N_2 gas indicates the presence of sulfides.

35. The reaction is specific for sulfides. Neither sulfur, sulfites, nor sulfates will react. The reaction is:

$$2NaN_3 + I_2 \longrightarrow 2NaI + 3N_2$$

Sulfides do not enter the reaction but act as a catalyst and are necessary for the reaction to proceed.

Elemental sulfur (Fliermans and Brock 1973)

36. Concentrations of 1 to 10 mg sulfur per gram of soil: Weigh 10 g of soil into a 250-ml screw-cap flask. Add 100 ml of carbon disulfide, cover tightly, and shake mechanically for 24 hr. Allow the mixture to settle and determine absorption at 382 nm on a spectrophotometer. Calculate the concentration of sulfur from the standard curve. A straight line is obtained for the range of 0 to 10 mg sulfur per gram of soil.

37. Lower concentrations of sulfur:

Reagents:

- Petroleum ether.
- NaCN solution: Dissolve 1 g of NaCN in 1 ℓ of a 19:1 mixture of acetone and water.
- 19:1 acetone-water mixture.
- Ferric chloride solution: Dissolve 0.5 g of $FeCl_3 \cdot 6H_2O$ in 100 ml of the 19:1 acetone-water mixture. Filter the solution after 48 hr. Reagent stable for several weeks.

38. Evaporate the carbon disulfide soil extract to dryness in a beaker under a hood (room temperature overnight). Dissolve the extracted sulfur in 40 ml of petroleum ether; transfer quantitatively to a 50-ml volumetric flask; make to volume with petroleum ether; and mix thoroughly. Pipette an aliquot containing 50 μg/ml of sulfur or less into a 25-ml volumetric flask, add 15 ml of the NaCN solution, and mix. After 2 min, make to volume with the acetone-water mixture and mix. Transfer 5 ml to a matched colorimeter tube, add 5 ml of the ferric chloride solution, and measure optical density at 465 nm. Compare with a set of similarly treated standards of elemental sulfur dissolved in petroleum ether. Beer's Law is followed over the range of 2 to 50 mg of sulfur per millilitre.

Pyrite

39. Separation of pyrite and analysis as iron (Begheign, van Breeman, and Velthorst 1978): Place 100 mg of soil in a 35-ml platinum crucible. Add 3 ml of HF and 1 ml of H_2SO_4 and swirl for exactly 1 min without heat. Transfer the mixture quantitatively to a quartz beaker containing 10 ml of a saturated boric acid solution (complex any remaining HF) and 1 ml of HCl and boil for 2 min. Transfer the mixture quantitatively to a centrifuge tube and separate the residue (pyrite) from the supernatant solution by alternately centrifuging and washing. The liquid contains ferric iron and nonpyritic ferrous iron. Wash the residue into a 50-ml porcelain dish with 10 ml of HNO_3. Evaporate the mixture to dryness on a steam bath and extract the residue with 5-ml aliquots of 4 M HCl. Transfer the extract to a volumetric flask, make to volume, and analyze the solution for iron on an atomic absorption spectrophotometer. From the iron concentration, calculate as either percent pyrite or percent sulfur. Alternatively, the determination of sulfate-sulfur in the same extract provides an estimate of pyritic, organic, and elemental sulfur.

40. Separation of pyrite and analysis as iron (Petersen 1969): Weigh 5 to 10 g of soil into either an extraction thimble or directly into the extraction cup on a bed of glass wool. Cover the soil with a layer of glass wool, place into a Soxhlet extractor, and extract the soil for 15 hr with 150 ml of 20 percent HCl. Replace the original extracting flask with one containing 150 ml of 68 percent HNO_3 and continue the extraction for an additional 15 hr. Use glass beads to prevent bumping.

41. Transfer the extract to a porcelain evaporating dish and evaporate

to dryness on a steam bath. Add 75 ml of 20 percent HCl and heat to dryness. Dissolve the residue in 20 percent HCl, transfer quantitatively to a volumetric flask, make to volume, mix, and analyze for iron by atomic absorption. Calculate as either percent pyrite or percent pyrite sulfur from the iron content.

42. Oxidation of pyrite with hydrogen peroxide (Barnhisel 1976c): The procedure of Ford and Calvert (1970) is essentially the same as that of Barnhisel (1976c) and could be used to estimate quantitatively the level of pyrite present by measuring either the acidity produced or the sulfates formed by the oxidation.

Reagents:

- Hydrogen peroxide: 30 percent
- NaOH standard: Dissolve 0.8 g of NaOH in 1 ℓ of distilled water.
- Determine normality by standardizing with either potassium acid phthalate or a known standard acid.

43. Weigh the soil sample (1 to 5 g) into a 500-ml digestion flask or beaker. Place in a water bath at 50°C and add 10 ml of hydrogen peroxide. After the reaction has stopped, add another 10-ml increment of hydrogen pyroxide. Continue the process until 120 ml of hydrogen peroxide has been added. Keep in the water bath for 4 hr, then remove, and let the mixture set over night. Boil the mixture on a hot plate until all effervescence stops, but do not evaporate to dryness. Cool to room temperature and filter into a 100-ml volumetric flask. Wash the residue and flask with distilled water so as to quantitatively transfer the filtrate from the digestion flask to the volumetric flask. Make to volume with distilled water and mix thoroughly.

44. Then either titrate an aliquot of the filtrate with the standardized NaOH to pH 7.0

$$\text{Pounds of } CaCO_3 \text{ per acre} = \frac{\text{Millilitres of NaOH} \times \text{N of NaOH} \times 50 \times 20 \times 100}{\text{Weight of sample represented by aliquot}}$$

or analyze an aliquot for SO_4-S by any of the methods listed under the section on sulfates. From the sulfate concentration, calculate as either percent pyrite or percent pyrite sulfur.

45. Comments. If oxidation of organic matter is not complete, organic acids will give high readings for the titration with NaOH. Estimation of percent pyrite from sulfates produced will be high if the soil contains considerable organic matter as organically bound sulfur also will be measured.

Sulfates

46. For accuracy, large quantities of ferric ions should be removed from solution. One of the easier ways is to reduce the ferric iron to ferrous iron with powdered aluminum or some other reducing agent.

47. Indirectly as barium by atomic absorption (Hue and Adams 1979):

Reagents:

- Ba stock solution (1000 ppm Ba): Dissolve 1.7786 g of $BaCl_2 \cdot 2H_2O$ in 1 ℓ of distilled water. Prepare working standards of 100 and 250 ppm Ba in distilled water.
- SO_4 stock solution (1000 ppm SO_4): Dissolve 1.814 g of K_2SO_4 in 1 ℓ of distilled water. Prepare a series of working standard containing from 0 to 40 ppm SO_4 in distilled water.
- $ClCH_2COOH$-KOH solution: Dissolve 47.25 g of $ClCH_2COOH$ in distilled water. Add 3.4 g of KOH and dilute to 250 ml with distilled water.
- $BaSO_4$ seed solution: Add 0.1 g of $BaSO_4$ powder to 100 ml of distilled water. Shake well before use.
- 95 percent ethanol.

48. Pipette 10 ml of the solution containing from 1 to 20 ppm SO_4 into a 50-ml Erlemeyer flask containing 3 ml of the 100 ppm barium standard (for solutions containing 20 to 40 ppm SO_4, use 3 ml of the 250 ppm barium standard). Add 2 ml of $ClCH_2COOH$-KOH solution, 0.1 ml of the barium seed solution, and 15 ml of 95 percent ethanol; cover tightly and shake for 15 min.

49. Transfer the suspension to a centrifuge tube, stopper the tube, and centrifuge at 5000 g for 30 min at 5°C. Determine the concentration of barium in the supernatant liquid by atomic absorption spectroscopy using a N_2O - acetylene flame.

50. Prepare a set of standards containing from 0 to 20 ppm barium by adding appropriate volumes from the 100 ppm barium standard to a 100-ml volumetric flask. Add 6.7 ml of $ClCH_2COOH$-KOH solution and 50 ml of 95 percent ethanol and make to volume with distilled water.

51. Calculate SO_4 in the extract from the amount of barium remaining in solution subtracted from the quantity of barium added.

52. Turbidimetrically as $BaSO_4$ (Page 1970):

Reagents:

- Sulfur stock solution (1000 ppm sulfur): Dissolve 5.4351 g of K_2SO_4 in 1 ℓ of solution (should be as near as possible the same as the soil extract).
- Dilute sulfur stock solution (100 ppm sulfur): Dilute 20 ml of stock solution to 200 ml with soil extract.
- Working sulfur standards: Pipette 0, 2, 5, 10, and 20 ml of the dilute sulfur stock solution into 100-ml volumetric flasks and make to volume with soil extract. The standards contain from 0 to 20 ppm sulfur per millilitre.
- Barium chloride: Dissolve $BaCl_2 \cdot 2H_2O$ in distilled water (1:4 ratio).
- Dispersion solution: Dissolve 79 g of NaCl in 300 ml of distilled water. Add, in order, mixing thoroughly before adding the next compound, 50 ml of glycerine and 100 ml of 95 percent ethanol.
- $BaCl_2$ seed solution: Just prior to use, add 1 ml of the 1000 ppm sulfur stock solution to 100 ml of the barium chloride solution, dropwise with constant stirring. Discard any of the mixture not used.

53. Mix together the dispersion solution and the barium chloride seed solution in a 1:5 ratio by volume. Add 1 ml of the mixture to a glass cuvette. Then add 4 ml of sample (or standard) with a pipette directly into the 1 ml of the barium chloride-dispersion solution mixture so as to ensure a thorough and rapid mixing. Mix thoroughly with a Vortex mixer and allow the precipitate to form for a minimum of 30 min. Prepare a set of standards as outlined under Procedure (paragraph 50).

54. After setting for 30 min, disperse thoroughly with a Vortex mixer and read optical density on a spectrophotometer at 420 mu. From the standard curve, convert to ppm S.

Stepwise Procedure for Analysis of Acid Sulfate Soils

55. The procedure is as follows:

a. Determine soil pH.

b. Determine lime requirement with one of the buffers using the double-buffer technique.

c. Determine if sulfides are present by the sodium azide test.

d. Determine if the soil is an acid sulfate soil by treating it with H_2O_2 until all reaction stops. Check the filtrate for pH and SO_4-S levels. If the pH is above 3.0 and low in SO_4-S, no further tests are needed; it is not an acid sulfate soil. However, if steps c and d indicate that the soil contains appreciable quantities of iron sulfides, then go to step e.

e. Extract and determine the concentration of water-soluble and exchangeable sulfates.

f. Extract and determine the concentration of elemental sulfur.

g. Determine the concentration of pyrite by:

- Extraction and removal of all ferric and non-pyritic ferrous iron. Dissolve the pyrite and determine the concentration by either analysis of iron in the pyrite, or analysis of total sulfates (sulfate content from steps e and f).
- Oxidation with H_2O_2 and determine the pyrite content from titration of acidity produced, and analysis of total sulfates (sulfate content from steps e and f).

Acidity Potential

56. It has been estimated that the complete oxidation of each 1% pyrite in soils would require 40 tons of lime per hectare (15 tons/acre) to maintain soil pH. Therefore, the total lime requirement for an acid sulfate soil is the sum of:

a. Lime requirement estimated by step b above × (1.2 to 1.5).*

b. Percent pyrite × 40 tons/hectare (or 15 tons/acre) × 0.X.**

57. The fact that sulfides do not oxidize as completely under field conditions as in the laboratory has been attributed to:

a. Larger particle size or smaller surface areas (van Breemen 1973).

b. Higher soil pH.

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* Due predominately to the unequal distribution of lime in the field, laboratory estimates of lime requirement have to be increased by a factor of from 1.2 to 1.5.

** Laboratory analysis of sulfides predicts higher lime requirements than found under field conditions. Therefore, the predicted lime requirement from sulfides should be reduced for field applications. The 0.X value indicates that this factor has not been established. It is an area of research that needs investigation.

c. A protective coating of Fe_2O_3 at higher soil pH's (Hodges 1977).

d. High levels of available phosphorus (Harmsen 1954).

e. Reduced oxygen diffusion rates in soil (van Breemen 1973).

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